Environment Canada
Environnement Canada

Environmental Protection
Operations Directorate

Direction générale des
activités de protection
de l'environnement

# CHARACTERIZATION AND TOXICITY TESTING OF FISH PROCESSING PLANT EFFLUENT IN CANADA

**Surveillance Report EPS-5-AR-07-03**
**Atlantic Region**

Canada

## ENVIRONMENTAL PROTECTION REPORT SERIES

Surveillance reports present the results of monitoring programs carried out by the Environmental Protection Operations Directorate. These reports are published on a regular basis.

Other categories in the EPOD series include such groups as Regulations, Codes and Protocols; Policy and Planning; Economic and Technical Appraisal; Technology Development; Briefs and Submissions to Public Inquiries; and Environmental Impact and Assessment.

Inquiries pertaining to Environmental Protection Operations Directorate Reports should be directed to:

Environment Canada
Environmental Protection Operations Directorate
Atlantic Region
16th Floor, Queen Square
45 Alderney Drive
Dartmouth, Nova Scotia
B2Y 2N6

Cat. No.: En83-3/2007-3E
ISBN: 978-0-662-47189-9

2008-03895/

# CHARACTERIZATION AND TOXICITY TESTING OF FISH PROCESSING PLANT EFFLUENT IN CANADA

B. A. Lalonde, C. A. Garron and W. Ernst

Environmental Protection Operations Directorate
Environment Canada
Atlantic Region

October 2007
EPS 5-AR-07-03

## ABSTRACT

Canada has one of the world's most valuable commercial fishing industries. In 2005, Canada exported 700,003 tonnes of fish products, valued at $4.3 billion. Fish and fish processing is of national importance, with over 1400 processing plants nationwide. The number of fish processing plants in Canada has continued to grow since only 460 fish processing plants were enumerated in 1990. There are approximately 800 fish processing plants in New Brunswick, Nova Scotia, Prince Edward Island and Newfoundland and Labrador while British Columbia has approximately 200 facilities. The province of Québec has at least 130 fish processing plants. Fish processing facilities in Canada range in size from a few employees to over one thousand employees.

Historically, the characterization of the effluent from fish processing has focused mainly on a few conventional characteristics such as biological oxygen demand (BOD), total suspended solids (TSS), nitrogen and oil and grease. Furthermore, only a few studies have looked at the toxicity of this type of effluent. Very little is known about the overall potential impact of those wastes to the environment.

To enable a better understanding of the environmental impacts of fish processing, Environment Canada- Atlantic Region conducted an enhanced effluent characterization study of fish processing plant effluents in Newfoundland, Nova Scotia, New Brunswick, Prince Edward Island, Québec and British Columbia from 2003 to 2007. A total of 22 plants participated in the study.

Final effluent samples from the fish processing plants were collected for toxicity testing and physical and chemical analyses. Toxicity tests performed on the samples included a Microtox™ acute test, a sea urchin fertilization test, a threespine stickleback survival test, a rainbow trout acute lethality test and a seven day growth and survival test using inland silversides. Physical and chemical analyses conducted included: ammonia, biochemical oxygen demand, total organic carbon (TOC), total solids, TSS, hardness, total nitrogen, nitrate, nitrite, total phosphorus, conductivity, oil and grease, PCBs, organochlorine pesticides, PBDEs and, total mercury.

Comparison of loadings (BOD, TSS, oil and grease) for fish processing revealed that more than half of the samples collected had higher loadings then the EPA effluent limitations (US EPA 1995). In terms of toxicity, 25% of the samples submitted for toxicity testing revealed no toxicity while 18% showed high toxicity ($LC_{50}$<10%, Sandhu 1979). BOD and oil and grease were the best predictors of toxicity using simple regression analysis. Another predictor of toxicity was the type of product processing with tertiary processing (most elaborate processing type) having the highest effluent toxicity. Toxicity of the effluent was also linked to the cleaning of the plants (i.e. when no processing was occurring). Finally it was also shown that a dissolved air flotation treatment at one plant decreased toxicity of the effluent but some level of toxicity remained.

**RESUME**

L'industrie de la pêche commerciale canadienne compte parmi les plus riches au monde. En 2002, le Canada a exporté 700 003 tonnes de produits de la pêche dont la valeur s'élevait à 4,3 milliards de dollars. Le poisson et sa transformation, pratiquée dans plus de 1 400 usines réparties dans tout le pays, revêtent une importance nationale. Le nombre d'usines de transformation du poisson, qui ne s'élevait qu'à 460 au moment du dénombrement de 1990, a continué de s'accroître au cours des dernières décennies. On compte maintenant quelque 800 usines au Nouveau-Brunswick, en Nouvelle-Écosse, à l'Île-du-Prince-Édouard et à Terre-Neuve-et-Labrador, 200 en Colombie-Britannique et au moins 130 au Québec. La taille des installations canadiennes de transformation du poisson varie d'usines comptant quelques employés à d'autres pouvant en compter plus d'un millier.

La caractérisation des effluents de la transformation du poisson mettait antérieurement l'accent sur quelques paramètres classiques tels la demande biologique en oxygène (DBO), les matières totales en suspension (MTS), l'azote, les huiles et les graisses. En outre, un nombre restreint d'études ont été effectuées sur la toxicité de ce type d'effluents. On connaît donc peu de choses des incidences possibles de ces déchets sur l'environnement.

Afin de mieux comprendre les activités de transformation du poisson et leurs effets possibles sur l'environnement du Canada, les services d'Environnement Canada de la Région de l'Atlantique ont réalisé, de 2003 à 2007, une étude approfondie de la caractérisation des effluents des usines de transformation du poisson situées à Terre-Neuve, en Nouvelle-Écosse, au Nouveau-Brunswick, au Québec, en Colombie-Britannique et à l'Île-du-Prince-Édouard. En tout, 22 usines ont participé à l'étude jusqu'en juin 2007.

Des échantillons d'effluents finaux des usines ont été prélevés pour la réalisation d'essais de toxicité et d'analyses physiques et chimiques. Les essais de toxicité effectués sont l'essai de toxicité aiguë Microtox™, un essai de fécondation de l'oursin de mer, un essai de survie de l'épinoche à trois épines, un essai de létalité aiguë chez la truite arc-en-ciel et un essai de croissance et de survie sur sept jours chez des capucettes. Les analyses physiques et chimiques ont porté sur l'ammoniac, la demande biochimique en oxygène, le carbone organique total (COT), les matières totales, les MTS, la dureté, l'azote total, le nitrate, le nitrite, le phosphore total, la conductivité, les huiles et les graisses, les BPC, les pesticides organochlorés, les PBDE et le mercure total.

La comparaison des charges (DBO, MTS, huiles et graisses) a montré que plus de la moitié des échantillons présentaient des charges supérieures aux valeurs limites fixées par l'EPA américaine pour les effluents (US EPA, 1995). Pour ce qui est de la toxicité, 25 % des échantillons soumis aux essais ne présentaient pas de toxicité et 18 % présentaient une toxicité élevée toxicity ($LC_{50}$<10%, Sandhu 1979). L'analyse de régression simple a montré que la DBO et la teneur en huiles et en graisses étaient les meilleurs prédicteurs. Un autre prédicteur de la toxicité était le type de transformation effectuée, la transformation tertiaire (la plus poussée) donnant les effluents les plus toxiques. La toxicité des effluents était aussi liée au nettoyage des usines (c.-à-d. en l'absence de transformation). Enfin, il a aussi été montré que le traitement par flottation à l'air dissous effectué à une usine réduisait la toxicité des effluents, mais non complètement.

**ACKNOWLEDGEMENTS**

The authors would like to thank all of the individual fish plant operators who voluntarily participated in this study. Without their cooperation none of this data could have been collected.

Sandi MacPherson, Colleen McNeil, Glenn Worthmann, Jerry Pulchan, Lyndsay Greenwood, Emma Stea, Jen-ni Kuo are kindly thanked for their participation in the field component of this project. As well, we would like to thank the following reviewers; Marie-Hélène Thériault, Simon Courtenay, Snehal Lakhani and Jocelyne Hellou.

## Table of Contents


1.0 INTRODUCTION ..... 9

2.0 METHODS ..... 11

**2.1** Effluent Sample Collection ..... 11
**2.2** Physical and chemical Analytical Methods ..... 12
**2.3** Toxicity Test Methods ..... 13
**2.4** Questionnaire and Interviews ..... 13

3.0 RESULTS ..... 14

**3.1** Effluent Characterization ..... 14
**3.1.1** Field Measurement ..... 14
**3.1.2** Conventional Parameters ..... 14
**3.1.3** Mercury ..... 16
**3.1.4** Persistent Organic Pollutants ..... 17
**3.1.5** Polybrominated Diphenyl Ethers ..... 17
**3.1.6** Comparison of effluent characteristics as a function of species ..... 18
**3.1.7** Correlations between effluent characteristics ..... 20
**3.2** Effluent Toxicity ..... 20
**3.2.1** Toxicity of All Effluents ..... 20
**3.2.2** Sea Urchin Fertilization $IC_{50}$ ..... 21
**3.2.3** Microtox™ $IC_{50}$ ..... 22
**3.2.4** Three-spine stickleback $LC_{50}$ ..... 23
**3.2.5** Inland silverside $LC_{50}$ ..... 23
**3.2.6** Rainbow trout $LC_{50}$ ..... 24
**3.2.7** Comparison of toxicity as a function of taxa ..... 25
**3.2.8** Correlations between toxicity test results ..... 26
**3.2.9** Regressions between effluent characteristics and toxicity tests ..... 26
**3.2.10** Comparison between plants processing same species (or taxa) ..... 28
**3.3** Comparison by Processing Categories ..... 32
**3.4** Results from Questionnaires ..... 35

4.0 DISCUSSION ..... 39

**4.1** Effluent Characterization ..... 39
**4.1.1** Field Measurement ..... 39
**4.1.2** Conventional Parameters ..... 39
**4.1.3** Persistent Organic Pollutants ..... 45
**4.1.4** PBDEs ..... 46
**4.1.5** Mercury ..... 47
**4.2** Effluent Toxicity ..... 47
**4.2.1** Relationships between effluent characteristics and toxicity ..... 49
**4.3** Comparison by processing categories ..... 50
**4.4** Effect of Effluent Treatment ..... 50

5.0 RECOMMENDATIONS ..... 52

6.0 REFERENCES ..... 53

## LIST OF TABLES

Table 2. 1 Types of Fish Processing Plants Sampled (2003-2005) ..... 11
Table 3. 1 Range of Field Measurements of Final Effluent ..... 14
Table 3. 2 Effluent Characteristics ..... 14
Table 3. 3 Sum of PBDEs in fish processing effluent ..... 18
Table 3.4 Simple Regression Results ..... 26
Table 3. 5 Stepwise regression on the principal component factors ..... 28
Table 3. 6 Effluent characteristics for sea cucumbers processing plants ..... 31
Table 3.7 Effluent characteristics for farmed salmon processing plants ..... 32
Table 3. 8 Category of processing, 1 indicating a primary processing, 2 indicating a secondary processing and 3 a tertiary processing. ..... 33
Table 3.9 Summary of results from questionnaire ..... 36
Table 4. 1 Range of fish processing effluent characteristics ..... 41
Table 4. 2 Effluent loadings and limitations for Molluscs and Crustaceans ..... 43
Table 4. 3 Effluent loadings and limitations for Groundfish ..... 44
Table 4. 4 Effluent loadings and limitations for Finfish ..... 44
Table 4. 5 PBDEs concentrations in surface water and effluent ..... 46
Table 4.6 Toxicity Test Results ..... 48
Table 4. 7 Toxicity Classification (Sandhu 1979) ..... 49

## LIST OF FIGURES

Figure 3. 1 Concentrations of mercury in effluent ..... 17
Figure 3. 2 Boxplots of effluent characteristics concentrations as a function of taxa (note number of observation above each box plot) ..... 19
Figure 3. 3 Boxplots of all toxicity tests. ..... 21
Figure 3. 4 Sea urchin fertilization $IC_{50}$ ..... 22
Figure 3. 5 Microtox™ $IC_{50}$ ..... 22
Figure 3. 6 Stickleback $LC_{50}$ ..... 23
Figure 3. 7 Inland silverside $LC_{50}$ ..... 24
Figure 3. 8 Rainbow trout $LC_{50}$ ..... 24
Figure 3. 9 Boxplots of toxicity testing results as a function of taxa (note that y axis is %dilution of effluent) ..... 25
Figure 3. 10 Principal components of the physical and chemical parameters ..... 27
Figure 3. 11 Log transformed concentrations of physical and chemical parameters as a function of category of processing. (Note number of observations above box plots) ..... 34
Figure 3. 12 Percent effluent concentrations of all toxicity tests as a function of category of processing ..... 35
Figure 4. 1 Scatterplot of total nitrogen (TN), ammonia (NH3) and nitrate (NO3) in the effluent samples ..... 40

**APPENDIX A - Questionnaire for Fish Processing Plants**
**APPENDIX B – Physical and Chemical and Toxicity Testing Results**
**APPENDIX C – Historical Physical and Chemical Effluent Characteristics**
**APPENDIX D – Calculations of Loadings**

## 1.0 INTRODUCTION

Canada has one of the world's most valuable commercial fishing industries. In 2005, Canada exported 703,000 tonnes of fish products, valued at $4.3 billion. The value ($) from exports was up 2.6 per cent from 2004.

Fish processing is of national importance, with over 1400 processing plants nationwide. The number of fish processing plants in Canada has continued to grow over the last few decades from 460 fish processing plants in 1990 (Novatec 1994). In 2003, there were over 800 fish processing plants in New Brunswick, Nova Scotia, Prince Edward Island and Newfoundland and Labrador while Ontario had 74 facilities and British Columbia had approximately 200 facilities. The province of Québec had over 130 fish processing plants. An exact number of fish processing plants in operation in Canada remains unknown because there is no country-wide database and also because individual plants have been known to open, close or change in ownership quickly. Fish processing facilities in Canada range in size from a few employees to over one thousand employees. During 2001, 30,000 workers were employed by the fish processors alone in Atlantic Canada.

In 2000, the Atlantic fishery accounted for 85% of total landings in Canada while the Pacific fishery accounted for 14% (AMEC 2003). The main species landed in the Atlantic fishery were shrimps, scallops, snow crab, lobster, herring, cod, flatfishes, salmon and mackerel (AMEC 2003) while the main species landed in the Pacific fishery were hake, Pacific herring, rockfish and salmon (AMEC 2003). The freshwater landings accounted for 1% of total landings with main species landed included pickerel, yellow perch, whitefish, northern pike and lake trout (AMEC 2003). Ontario and Manitoba have the bulk of the freshwater landings. The freshwater processing value accounted for 2.8% of the overall values. It is interesting to note that most processors are set-up to process many different types of fish (shellfish, pelagic, groundfish).

Fish processing techniques and the resulting effluent vary depending on species processed as well as the final product obtained (AMEC 2003). Some facilities screen their effluent in accordance with the *Fisheries Act* Guidelines (Environment Canada 1975) after which the final effluent is generally discharged directly into the marine environment. A few plants discharge into municipal effluent treatment systems. Up to 25% of plants (65 sites) in Nova Scotia and at least 3% of plants (4 sites) in New Brunswick are known to discharge their effluent into municipal waste water systems (AMEC 2003). In British Columbia, 42% of plants discharge to municipal systems while the remainder discharge either to the Fraser River (10%) or the marine environment (48%) (Novatec 1994). In Ontario, the majority of processing plants discharge to municipal systems (Anita Li, pers. comm.).

There is almost no information on actual quantities of effluent released to the environment from fish processors in Canada except in New Brunswick where the volumetric flow rate ($m^3$/day) is a main component of the Contaminated Process Water Report which has to be filed with the regulator (NBDELG) on a yearly basis. Of the limited dataset, the flow ranges from 0.11 to 3400 $m^3$/day (AMEC 2003). In British Columbia, water consumption for fish processing plants range from 0.2L/kg for molluscs to 326L/kg for salmon (Novatec 1994). Carawan (1991) and Park *et al.* (2001) have reported effluent flows from fish processing from 50 to 13 500 $m^3$/day with most of the higher flows were related to processing crustaceans and molluscs.

Historically, the characterisation of the effluent has focussed mainly on a few conventional parameters such as biological oxygen demand (BOD), total suspended solids (TSS), nitrogen and oil and grease (Kumbhare 1975, Gonzalez *et al.* 1983, NovaTec 1994, Anguiar and Sant'Anna 1998, Usydus and Bykowski 1999, Fahim *et al.* 2001, AMEC 2003,). Furthermore, only three studies have looked at the toxicity of this type of effluent. However, little is known about the overall hazard of the effluent.

In addition to conventional characteristics of fish processing effluent, there are other chemicals which may enter the effluent. A review of the Canadian Food Inspection Agency's (CFIA) Reference Listing of Accepted Construction Materials, Packaging Materials and Non-Food Chemical Products (2003), indicates that the following types of chemicals are allowed to be used in fish processing plants; cleaners, disinfectants, deodorizers, lubricants, pesticides, and sanitizers. These chemicals were placed on the approved list once it could be demonstrated that they were safe to use on machinery that process food for human consumption (Jack Donald, pers. comm. May 2005). The approval of these chemicals did not require environmental evaluations. Usage pattern information of these chemicals (type, quantity) is not collected by the CFIA (Jack Donald, pers. comm.). In Walsh *et al.* (2004), a listing of chemicals (and some quantities) used at four fish processing plants in the Atlantic Provinces was reported. Chemicals usage patterns and active ingredients were also determined for 8 plants sampled by Environment Canada in 2004 and 2005. There were more than 50 active ingredients (substances) in the 46 chemicals reported to be in use at 8 seafood processing plants. Some of these substances met the categorization criteria under *CEPA* (1999) (Environment Canada 1993) for their values of persistence, bioaccumulation and inherent toxicity. Given that the active ingredients listed in the table were for only eight out of over 1,300 plants, it is likely that complete survey of the industry would reveal many other chemicals which have been found to meet the categorization criteria.

Health Canada has also approved 217 substances that can be used as chemical additives for use in fish processing. These chemicals are used for a variety of applications; preservatives, gelling agents, glazing agents, firming agents, pH adjusting agents, colouring agents, emulsifying agents and texturizers. These additives could end up in the final effluent. A complete listing of these chemicals can be found in the AMEC (2003) report. Information on quantities of these substances discharged isn't available at the present time.

To enable a better understanding of the potential environmental impacts of fish processing fish in Canada, Environment Canada- Atlantic Region conducted an enhanced effluent characterization study of fish processing plant effluents from April 2003 to June 2007.

## 2.0 METHODS

### 2.1 Effluent Sample Collection

Twenty two plants from the four Atlantic provinces, Québec and British Columbia participated in the study (Table 2.1). The intent of the study was to more clearly characterize effluents from fish processing activities and to evaluate their potential effects on the environment.

Final effluent samples from the fish processing plants were collected with Sigmamotor 900 Series Automated samplers. Composite samples were collected over the daily plant production period and up to 24 hours. Depending on the schedule of the processing plants, the composite samples sometime included the washdown portion of the work schedule (Table 2.1). Sampling occurred at a location downstream of any treatment (screening, rotating screen, dissolved air flotation) conducted by the plant and before discharging to the environment or to a municipal system (Table 2.1).

**Table 2. 1 Types of Fish Processing Plants Sampled (2003-2007)**

| Organisms Processed (3 of plants) | Province | Sample include washdown ?* | Volume processed tonnes/day | Type of processing |
|---|---|---|---|---|
| Lobster (3) | NS, PEI, NB | Yes (2) No (1) | 6.8-22.7 | Cooked; breaking, cooking. Fresh, frozen (split), raw claws and minced meat |
| Snow Crab (3) | NS, NB, Qc | No (2) Yes (1) | n/a – 13.6 | Butchering of raw and cooked |
| Clam (1) | NS | No | n/a | Fresh or chilled (in shell or meat) |
| Mussel (1) | PEI | Yes | n/a | Fresh or chilled (in shell) |
| Frozen Pollock (1) | NS | No | n/a | Fillets (dried and salted) |
| Herring (2) | NB, NS | Yes | 9.5-500 | Fresh and frozen; whole and cutting; canned, dressed, fillet and smoked. |
| Jonah Crab (1) | NS | No | 9 | Shell on, cooked and extraction, frozen |
| Scallop (1) | NS | No | 225 | Washed and graded (raw and frozen) Shucked at sea |
| Algae *** (1) | NS | Yes | 22.7 | Cooking, Drying, grinding, extracts. |
| Salmon Fillet – smoked *** (1) | NS | Yes | 18 | Oven and cold smoked, brining. |
| Sea cucumber (1) | NL | No | 9 | Fresh – meat (body walls) |
| Yellowtail flounder (1) | NL | No | 50 | Fillets, fresh and frozen (stuffed and breaded fillets) |
| Herring + Fish meal (1) | NS | No | 107 | Fillets (fresh, frozen, marinated, salted); Fishmeal |

| Organisms Processed (3 of plants) | Province | Sample include washdown ?* | Volume processed tonnes/day | Type of processing |
|---|---|---|---|---|
| Cod (1) | NS | No | 6.8 | Breaded and/or battered cod strips (some cutting) |
| Shrimp** (1) | NB | No | 68 | Fresh and frozen; Cooked and peeled |
| Redfish (1) | NS | Yes | 18 | Fresh, dressed, fillets |
| Salmon | BC (3) | Yes (1) and No (2) | Up to 90 | Fresh, dressed, fillets |
| *Washdown; no processing involved. The work involves the disinfection, sanitization of equipment<br>**grab sample since processing effluent was treated before discharge into environment<br>*** effluents from these plants were discharged to a municipal wastewater treatment plant | | | | |

Two automated samplers were used for the collection of each sample. One of the samplers was equipped with Teflon tubing and a hexane rinsed 12L glass carboy which was surrounded by ice packs. That sample was analysed for numerous physical and chemical parameters, listed below. The second sampler was equipped with food-grade plastic tubing and deposited into a 120 L food grade plastic (polypropylene) drum. The effluent collected by this sampler was used for toxicity testing. Once the sampling was complete, the samples were stirred by hand, transferred into their proper shipment containers, labelled, and kept cool, prior to shipment to the laboratories. A chain of custody form and ice-packs were also included with all of the shipments. The following field measurements were obtained for each effluent samples; pH, dissolved oxygen, total chlorine, free chlorine, salinity, and temperature. The dissolved oxygen and temperature values were measured with a YSI™ portable $O_2$ meter. The salinity was measured with a hand-held refractometer while total chlorine, free chlorine and pH were measured with paper test strips.

## 2.2 Physical and chemical Analytical Methods

Physical and chemical analyses conducted included: ammonia, biochemical oxygen demand (BOD), total organic carbon (TOC), total solids, total suspended solids (TSS), hardness, total nitrogen, nitrate, nitrite, total phosphorus, conductivity, oil and grease (O&G), total and trace mercury and, organochlorines (including PCBs and pesticides). Polybrominated diphenyl ethers (PBDEs) were analysed for some of the samples obtained in 2004-2005. Except for PBDEs, all analytical tests were performed at Environment Canada's Environmental Quality Laboratory in Moncton, NB using standard protocols. The PBDE analysis was performed by AXYS (Sidney, BC) in accordance with the United States Environmental Protection Agency (EPA) draft method 1614 (EPA 2003).

## 2.3 Toxicity Test Methods

Aquatic toxicity can be measured using effluent samples obtained at the point of discharge and by conducting either short-term (acute) or long-term (chronic) toxicity tests on those samples. Results of such aquatic toxicity testing are often expressed as volumetric concentrations. For example, a reported 96-hour $LC_{50}$ for rainbow trout (*Oncorhynchus mykiss*) of 5% means that a test solution of 5% of the effluent being tested plus 95% dilution water was estimated to cause 50% of the test organisms (rainbow trout) to die after 96 hours of exposure. This method of reporting was used for this assessment. The test results labelled mortality-full strength are the percentage of organisms dead after exposure to full strength effluent.

Toxicity tests performed on the samples included a Microtox™ acute test, a sea urchin fertilization test ($IC_{50}$), a Threespine Stickleback survival test ($LC_{50}$) and a seven day growth and survival test using Inland Silversides ($IC_{50}$ and $LC_{50}$). If the salinity of the effluent was less than 10 ppt, samples were also subjected to rainbow trout acute lethality tests ($LC_{50}$). Rainbow trout, Microtox™ (*Vibrio fischeri*) and stickleback were also tested on full strength sample (full) and the percent mortality was determined. The silverside tests were performed by Stantec (Guelph, ON) and Bodycote Material (Québec, Qc) while all other toxicity tests were performed at Environment Canada's Environmental Quality Laboratory in Moncton, N.B. Sampling protocols for toxicity testing were in accordance with Environment Canada's protocols (EC 1990, 1992a, 1992b, 2000). The protocol for toxicity testing using Inland Silversides was in accordance with EPA-821-R-02-014. Some of the effluent samples were not submitted to the toxicity test with Stickleback due to lack of availability of Stickleback at certain times of the year. In these cases, a Rainbow trout survival test was used which also included an additional control test at the salinity of the undiluted test sample.

## 2.4 Questionnaire and Interviews

Questionnaires and interviews for each plant visited in 2004-2007 were completed by Environment Canada staff with processing plant employees. An example of the questionnaire is attached as Appendix A. Some of the information from the questionnaires is listed in Section 3.4

# 3.0 RESULTS

## 3.1 Effluent Characterization

### 3.1.1 Field Measurement

The results of field measurements taken at the time of effluent sampling are listed in Table 3.1. The full set of field measurement is listed in Appendix B with plants labelled alphabetically to ensure anonymity of the plants which voluntarily cooperated in this study.

**Table 3. 1 Range of Field Measurements of Final Effluent**

| Parameter | Units | Range of Values | Median |
|---|---|---|---|
| Free Chlorine | ppm | 0 – 0.5 | 0 |
| Total Chlorine | ppm | 0 – 0.5 | 0 |
| Dissolved oxygen | mg/L | 1.3 -13.1 | 9.94 |
| Temperature | °C | 2.8 – 25.5 | 10 |
| Salinity | ppt | 0 - 32 | 15 |

### 3.1.2 Conventional Parameters

The ranges and medians of the effluent characteristics from all the fish processing plants are listed in Table 3.2. The full set of analytical results is listed in Appendix B. The table compares concentrations of physical and chemical parameters measured in this study with existing Canadian Water Quality Guidelines for the Protection of Aquatic Life (CCME 1999). Since only two parameters measured during this study (pH and nitrate) have CCME guidelines for the protection of marine aquatic life, guidelines from other jurisdiction (Australia, US EPA) are also listed in table 3.2.

**Table 3. 2 Effluent Characteristics**

| Parameter | Units | Range of Values | Median | Guidelines values[1] |
|---|---|---|---|---|
| Total Hardness | mg/L | 5.19 - 5724 | 2975 | |
| Chloride | mg/L | 32.4 - 18558 | 9453 | |
| Sulphate | mg/L | 4.7 - 2444 | 1396 | |
| Nitrate | mg/L | 0.054 – 5.84 | 1.765 | 16[2] |
| Magnesium dissolved | mg/L | 0.46 - 1162 | 610 | |
| Potassium dissolved | mg/L | 3.02 - 544 | 221 | |
| Sodium dissolved | mg/L | 93.5 - 9915 | 5019 | |
| Calcium dissolved | mg/L | 1.32 – 503 | 228 | |
| Nitrogen, Ammonia | mg/L | 0.06 – 42.67 | 1.77 | 20-148 |
| Total Nitrogen | mg/L | <0.01 –154.3 | 19.91 | |
| Total Organic Carbon | mg/L | 3 - 1134 | 102.35 | |
| Phosphorous | mg/L | 0.162 - 81.98 | 5.841 | |
| Aldrin | ng/L | <ND (0.5 -11) | n/a | 10-1300 |

| Parameter | Units | Range of Values | Median | Guidelines values[1] |
|---|---|---|---|---|
| α-benzenehexachloride | ηg/L | < 0.5 - 36 | n/a | 129-160*10[3] |
| Alpha-chlordane | ηg/L | <ND (0.5 -11) | n/a | 4-90 |
| Gamma-chlordane | ηg/L | <ND (0.5 -14) | n/a | 4-90 |
| O,P'-DDD | ηg/L | <ND (0.5 -13) | n/a | 65-3600 |
| P,P'-DDD | ηg/L | <ND (0.5 -11) | n/a | 65-3600 |
| O,P'-DDE | ηg/L | <ND (0.5 -11) | n/a | 65-14000 |
| P,P'-DDE | ηg/L | < 0.5 - 139 | n/a | 65-14000 |
| O,P'-DDT | ηg/L | <ND (0.5 -11) | n/a | 1-130 |
| P,P'-DDT | ηg/L | <ND (0.5 -11) | n/a | 1-130 |
| Dieldrin | ηg/L | < 0.5 - 17 | n/a | 0.19 – 710 |
| Alpha-endosulfan | ηg/L | <ND (0.5 -51) | n/a | 8.7-34 |
| Beta-endosulfan | ηg/L | <ND (0.5 -14) | n/a | 8.7-34 |
| Endrin | ηg/L | <ND (0.5 -14) | n/a | 2.3-37 |
| Heptachlor epoxide | ηg/L | <ND (0.5 -11) | n/a | 3.6-53 |
| γ-benzenehexachloride | ηg/L | <ND (0.5 -11) | n/a | 3-160 |
| P,P'-methoxychlor | ηg/L | <ND (0.5 -15) | n/a | 30-40 |
| Mirex | ηg/L | <ND (0.5 -15) | n/a | 1 |
| Oil and Grease | mg/L | < 1 -1117 | 28 | |
| Total PCBs | ηg/L | < 1 - 233 | n/a | 1-10000 |
| Specific conductivity | us/cm | 771 - 46200 | 22280 | |
| pH | | 5.77 – 10.63 | 6.83 | 7-8.7[2] |
| BOD dissolved | mg/L | 24 - 4585 | 147 | |
| Total suspended solids | mg/L | < 1 -1280 | 7200 | |
| Total mercury | µg/L | <0.02 – 0.57 | 0.04 | 0.016 -2.1 |
| Total PBDEs | pg/L | 82.17-35055 | 5582 | |

Notes;
[1]Range of concentration in guidelines indicates a chronic (lowest number) and acute (highest number) exposure.
[2] CCME guidelines for protection of marine aquatic life

Values of major ions such as potassium, sodium, calcium, magnesium, sulphate and chloride range one to two orders of magnitude between samples. The wide range of values for these parameters was due to the difference in usage by plants of saltwater in their processing.

Some of the parameters such as BOD, TSS, oil and grease ranged a few orders of magnitude between plants. The highest concentrations of oil and grease were from plants processing snow crab (1117 mg/L) and herring (296 mg/L) while the lowest concentrations were from plants processing molluscs (<1.0 mg/L). Total suspended solids concentrations were highest at plants processing salmon (1280mg/L), snow crab (1192 mg/L), mussel (558.6mg/L), shrimp (479.4mg/L), herring (347 mg/L), yellowtail flounder (549mg/L) and sea cucumbers (693mg/L). Some inconsistencies existed in the data set. For example, one plant processing snow crab (Plant E) had the lowest level of TSS measured in this study (TSS = < 1 mg/L) while another plant processing salmon had 10 times less TSS (123mg/L) than plant S which had a concentration of 1280mg/L. A comparison of plants processing the same species is included in the Section 4.1. BOD concentrations were highest at plants processing snow crab (2230 mg/L), yellowtail flounder (2415 mg/L), sea cucumber (4585 mg/L) and shrimp (2062 mg/L). In general, high concentrations of BOD and TSS were recorded at the same plants.

Nitrate concentrations varied one to two orders of magnitude between processing plants. The highest level of nitrate was measured at a plant processing mussels (5.84mg/L). Only three (mussels, clams and lobsters) out of eighteen plants recorded detectable concentrations of nitrate in their effluent. Nitrate concentrations in all samples were below the Canadian Water Quality Guidelines for the protection of aquatic life in marine waters. Ten out of fifteen samples had pH levels which did not meet the Canadian Water Quality Guidelines.

Ammonia concentrations also ranged between one to two orders of magnitude between processing plants. The highest concentrations of ammonia were recorded for plants processing snow crab (42.67mg/L), Pollock (12.3 mg/L), shrimp (13.31 mg/L) and fish meal (12.83 mg/L). The highest concentrations of total nitrogen were recorded at plants processing snow crabs (131.3 mg/L), Atlantic salmon (145mg/L) and shrimp (154.3mg/L). Phosphorous concentrations in the effluent ranged from one to almost three orders of magnitude. The highest level was measured at a plant processing Cod (81.98mg/L)

NovaTec (1994) stated that high BOD was usually in close association with high ammonia. The correlation coefficient of the log transformed BOD and ammonia concentrations measured in this study was equal to 0.380 ($p=0.098$). Therefore this relationship between BOD and ammonia was not present in our study.

### 3.1.3 Mercury

Total mercury was also assessed in this study. The CCME interim guideline for the protection of aquatic life for mercury in marine waters is 0.016µg/L. The laboratory detection limit for mercury was 0.02µg/L. There were 17 out of 26 samples which had mercury concentrations higher than the CCME guideline (Figure 3.1). The highest level of total mercury was reported for a plant processing lobster (plant R = 0.57µg/L) which is over 35 times the guideline limit for the protection of aquatic life.

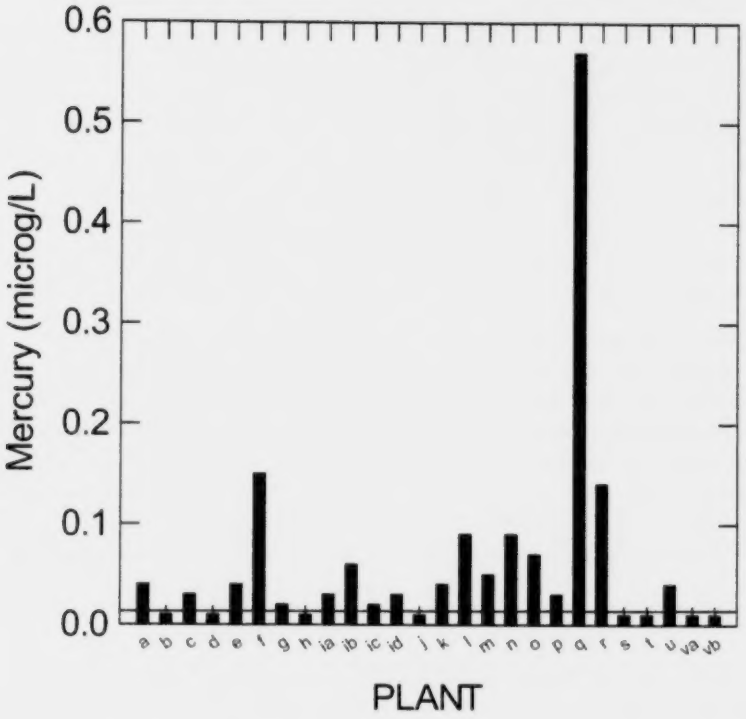


Figure 3. 1.Concentrations of mercury in effluent

### 3.1.4 Persistent Organic Pollutants

Persistent substances such as organochlorine pesticides and PCBs were only analysed in the first fourteen samples and discontinued after that since all but one of the samples had no detectable concentrations. Effluent from plant F had the following concentrations; Total PCBs = 233ηg/L, Alpha-benzenehexachloride = 36ηg/L, p-p"DDE = 139ηg/L, Dieldrin =17ηg/L. Comparison of that sample to guidelines from other jurisdiction (EPA) revealed three parameters for which exceedances were registered ; DDE, dieldrin and PCB.

### 3.1.5 Polybrominated Diphenyl Ethers

Effluents form plants processing herring, cod, shrimp, lobster Jonah crab, redfish, scallop and fish meal were sampled as part of this study. These plants are all located within Atlantic Canada. The results of the analysis on the total sum of PBDEs in fish processing effluent are presented in Table 3.3. The sums in Table 3.3 only include tri to deca-BDEs and are laboratory blank corrected.

**Table 3. 3 Sum of PBDEs in fish processing effluent**

| Species | Sum of PBDEs (pg/L) |
|---|---|
| Cod | 35055.28 |
| Shrimp | 14502.69 |
| Lobster | 12805.32 |
| Fish Meal | 6445.08 |
| Herring | 4603.92 |
| Jonah Crab | 4719.34 |
| Redfish | 1965.64 |
| Scallop | 82.17 |

The concentrations of total PBDEs ranged from 82.17 to 35055 pg/L in the nine samples submitted for analysis. The highest concentrations of total PBDE was from a plant processing cod while the lowest concentration of total PBDE was from a plant processing scallop. The sums of PBDEs were similar for the plant processing herring and the one processing Jonah crab (both around 5000 pg/L) while the effluents from plants processing shrimp and lobster had similar concentrations (between 12000 and 14000pg/L). The results from the plant processing algae were not complete since some of the individual compounds of PBDEs (PBDE 181, 183, 190, 203, 206, 207, 208, 209) could not be accurately quantified due to analytical difficulties.

### 3.1.6 Comparison of effluent characteristics as a function of species

Figure 3.1 depicts the relationship between taxa (same or similar group of organisms) and effluent characteristics. Taxa were pooled as: groundfish (pollock, cod, yellowtail flounder), molluscs (clam, mussel, scallop), crustacean ( lobster, snow crab, Jonah crab, shrimp), pelagic (herring, fish meal, salmon, redfish), others (sea cucumber, algae) (Table 1.1). All the data in Figure 3.2 were log transformed. Within each box plot of figure 3.2, the central line indicates the median value, and the edges of the box give the 1$^{st}$ and 3$^{rd}$ quartile, hence the box represents 50% of the data. The whiskers extend to the extreme low and high values.

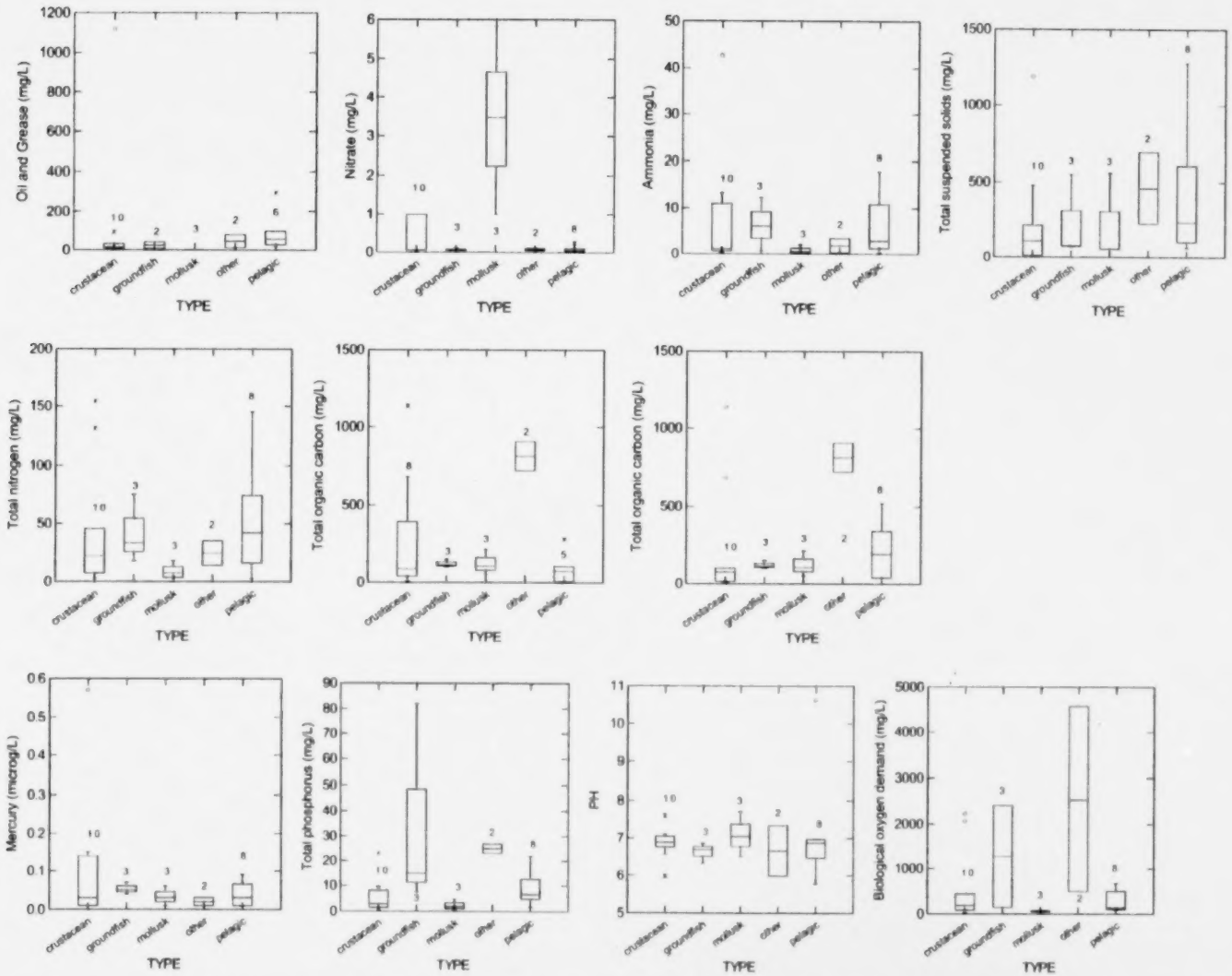


Figure 3. 2 Boxplots of effluent characteristics concentrations as a function of taxa (note number of observation above each box plot)

Higher concentrations of chloride, sulphate, nitrate, magnesium, potassium, sodium, calcium and conductivity were associated with the mollusc grouping. Some of these parameters were associated with salt water usage in the processing line while other parameters such as calcium and trace amounts of sulphate and magnesium may also be related to the composition of the organism's shell. Total suspended solids in all taxa were generally in the same range (Figure 3.2). Higher concentrations of ammonia and total nitrogen were mostly associated with the groundfish grouping (Figure 3.2). Ammonia is often associated with blood and slime from fish (Novatec 1994). POPs and PCB results were not associated with any particular grouping because only one sample showed detectable concentrations (snow crab plant). Mercury concentrations were also all in the same range when compared across groupings (Figure 3.2). There was not enough data points to perform the grouping analysis for PBDEs, organochlorine pesticides and PCBs.

### 3.1.7 Correlations between effluent characteristics

Simple correlations with post-test Bonferroni probabilities were obtained between all logarithmic transformed effluent characteristics. Only a few correlations had statistically significant (or near significant $p<0.1$) relationships between the parameters;

- Ammonia and total nitrogen (correlation coefficient = 0.849, p=0.024)
- Hardness, chloride, sulphate, magnesium, calcium and conductivity are all correlated with each other (all $p<0.05$). These correlation results are not surprising since calculations of hardness are based on major ions.
- BOD and TSS (correlation coefficient = 0.936, p=0.000)

## 3.2 Effluent Toxicity

### 3.2.1 Toxicity of All Effluents

The boxplots in Figure 3.3 below are a summary of all toxicity tests results from this study. The y axis of figure 3.3 represents the concentration which is lethal to 50% of test organisms. I_silverIC25 and I_silverLC50, are both chronic toxicity tests (using inland silversides) while all the other tests are acute toxicity tests. Within each boxplot, the central line indicates the median value, and the edges of the box give the 1$^{st}$ and 3$^{rd}$ quartile, hence the box represents 50% of the data. The whiskers extend to the extreme low and high values. The numbers of toxicity tests represented in the boxplots are listed above the individual boxplots. The individual tests are discussed in sections 3.2.2 to 3.2.5. The median value is lowest for the rainbow trout LC50 value while the highest median value is for the sea urchin IC50 test.

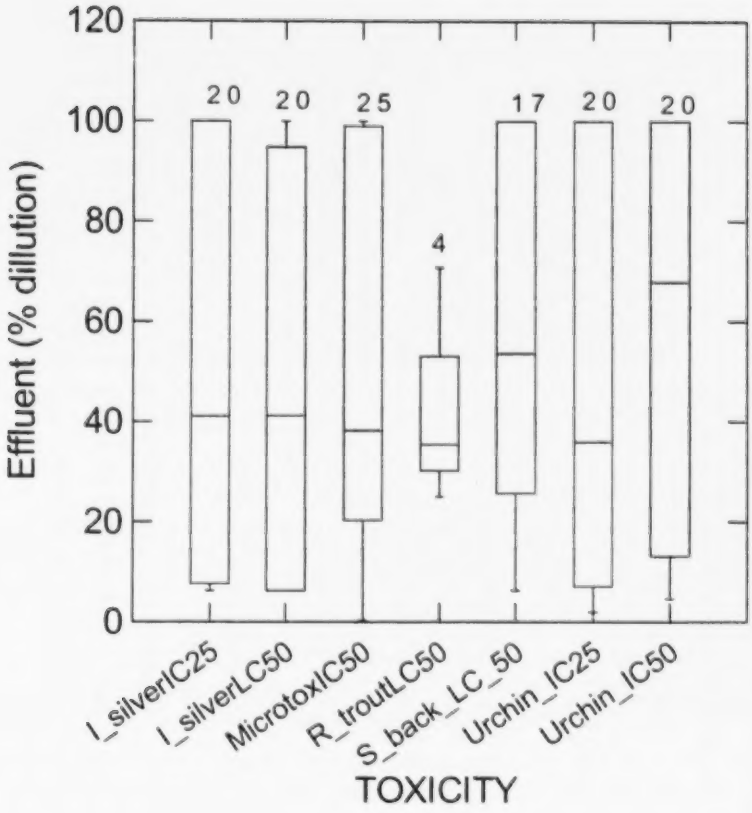


Figure 3. 3 Boxplots of all toxicity tests.

Figure 3.4 to 3.8 describe the results of the individual toxicity tests. Some of the effluent samples are missing some toxicity tests because of malfunction of sampling equipment, of holding time problems because of delivery mishaps or interference because of salinity.

### 3.2.2 Sea Urchin Fertilization $IC_{50}$

Six of the effluent sources showed no effects to sea urchin fertilization (Figure 3.4); Pollock, clam, mussel, lobster, Jonah crab and scallop. It is interesting to note that another toxicity test using effluent from lobster processing (LO3) did show some toxicity to sea urchin fertilization. Overall, the effluent from the following species caused the greatest impact on sea urchin fertilization; shrimp, snow crab, salmon, algae, fish meal and sea cucumber.

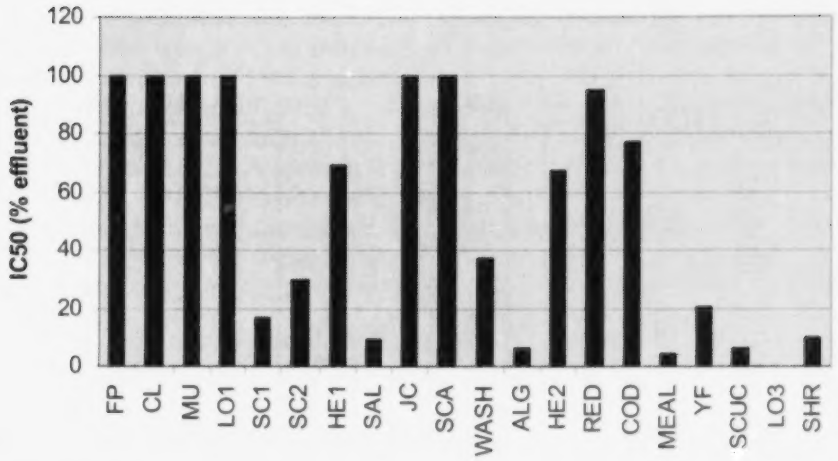


Figure 3. 4 Sea urchin fertilization $IC_{50}$
(FP; frozen pollock, CL; clam, MU; mussel, LO1; lobster, SC1; snow crab, SC2; snow crab, HE1; herring, SAL; salmon, JC; Jonah crab, SCA; scallop, WASH; washdown at lobster plant, ALG; algae, HE2; herring, RED; redfish, COD; cod, MEAL; herring/fish meal plant, YF; yellowtail flounder, SCUC; sea cucumber, LO3; lobster, SHR; shrimp)

### 3.2.3 Microtox™ $IC_{50}$

Eight effluent sources which showed no effects to *Vibrio fischeri* were from various species processed such as pollock, clam, mussel, Jonah crab, snow crab, scallop, fish meal and yellowtail flounder (Figure 3.5). It is interesting to note that the two herring effluents did show some toxicity to *Vibrio fischeri* in comparison to the fish (herring) meal effluent. It is notable that the IC50 for *Vibrio fischeri* and sea urchin fertilization were similar for most species. Possible correlation between toxicity tests are described in Section 3.6.2.

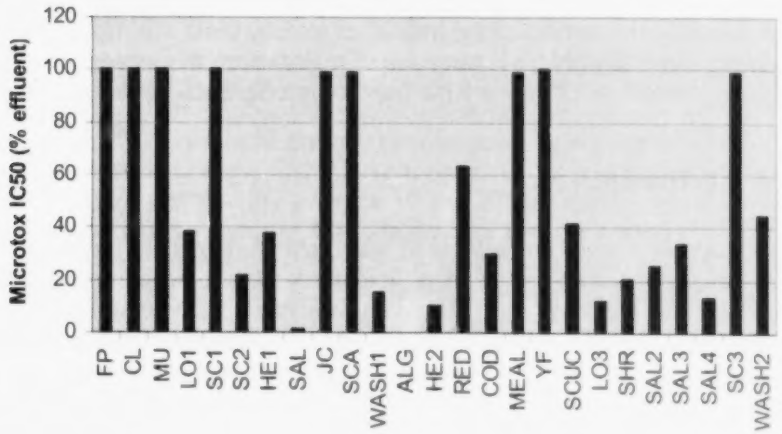


Figure 3. 5 Microtox™ $IC_{50}$
(FP; frozen pollock, CL; clam, MU; mussel, LO1; lobster, SC1; snow crab, SC2; snow crab, HE1; herring, SAL; salmon, JC; Jonah crab, SCA; scallop, WASH; washdown at lobster plant, ALG; algae, HE2; herring, RED; redfish, COD; cod, MEAL; herring/fish meal plant, YF; yellowtail flounder, SCUC; sea cucumber, LO3; lobster, SHR; shrimp, SAL2; salmon, SAL3; salmon, SC3; snow crab, WASH2; washdown at snow crab plant)

### 3.2.4 Three-spine stickleback $LC_{50}$

Pollock, clam and mussel processing effluents, which were not found to be toxic by the Microtox™ or the sea urchin fertilization tests, were also not toxic to the stickleback (Figure 3.6). In addition to these three effluent sources, the lobster (LO3) effluent and the washdown from the snow crab processing plant did not show any toxicity to the stickleback (Figure 3.6). It is interesting to note that the effluent (LO3) had showed some degree of toxicity to both sea urchin fertilization and *Vibrio fischeri* (Figures 3.4 and 3.5). Sea cucumber and one of the Atlantc salmon (SAL2) effluent showed the highest toxicity to the stickleback.

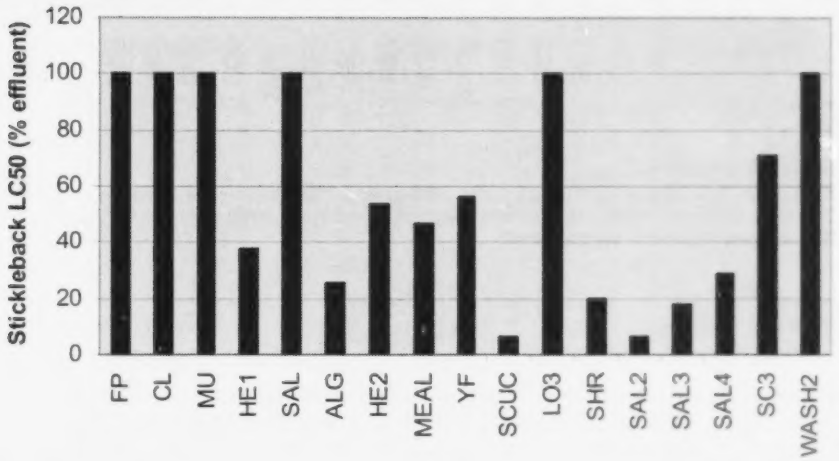


Figure 3. 6 Stickleback $LC_{50}$
(FP; frozen pollock, CL; clam, MU; mussel, HE1; herring, SAL; salmon, ALG; algae, HE2; herring, MEAL; herring/fish meal plant, YF; yellowtail flounder, SCUC; sea cucumber, LO3; lobster, SHR; shrimp; SAL2; salmon, SAL3; salmon, SC3; snow crab, WASH2; washdown at snow crab plant)

### 3.2.5 Inland silverside $LC_{50}$

The Inland silverside were able to survive up to 100% effluent from the following effluent sources; clam, mussel, lobster and redfish (Figure 3.7). The effluent from the plants processing the lobster (LO1) and redfish had previously showed some toxicity to other organisms. It is also interesting to note that although the effluent from the pollock processing did not previously demonstrate acute toxicity through the other tests it did have some toxicity (LC50 = 53.6) with the Inland silverside which is a chronic test. It is also interesting to note the large difference in toxicity from two effluent sources that processed snow crab. In Figure 3.7, the $LC_{50}$ from one plant processing snow crab approaches 90% while the two other $LC_{50}$ from plants processing snow crab as well is fewer than 10%. Shrimp, snow crab and Atlantic salmon effluent showed the highest toxicity to the inland silverside.

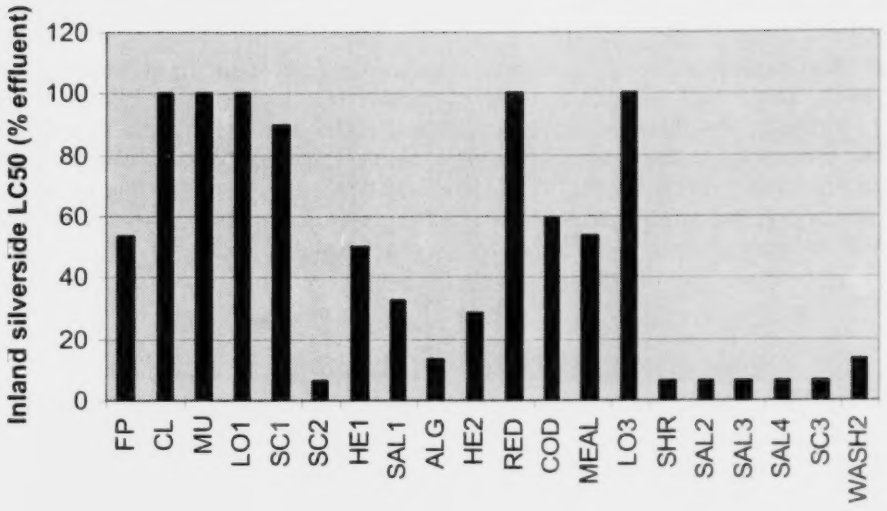


Figure 3. 7 Inland silverside $LC_{50}$
(FP; frozen pollock, CL; clam, MU; mussel, LO1; lobster, SC1; snow crab, SC2; snow crab, HE1; herring, SAL; salmon, ALG; algae, HE2; herring, RED; redfish, COD; cod, MEAL; herring/fish meal plant, LO3; lobster, SHR; shrimp; SAL2; salmon, SAL3; salmon, SC3; snow crab, WASH2; washdown at snow crab plant)

### 3.2.6 Rainbow trout $LC_{50}$

The response of rainbow trout to the effluent from four processors was varied with $LC_{50}$ ranging from over 20% to 70%. Although the effluent from the redfish processing was not toxic using the Inland silverside chronic toxicity test (Figure 3.7), the same effluent showed some toxicity (70% dilution) using the rainbow trout acute toxicity test (Figure 3.8). The effluent from the algae processing showed the highest toxicity to rainbow trout.

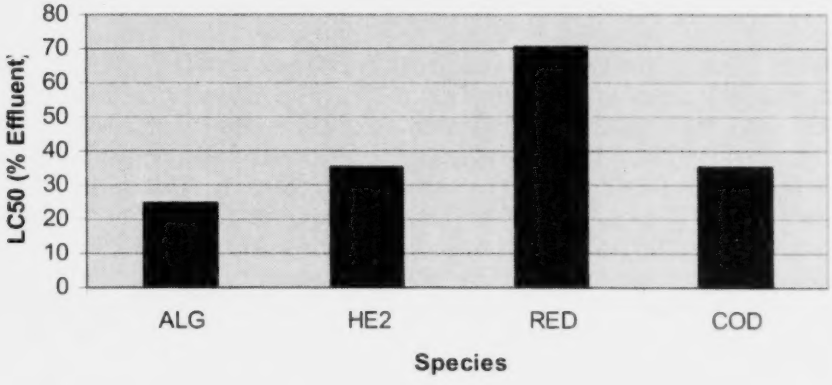


Figure 3. 8 Rainbow trout $LC_{50}$
(ALG; algae, HE2; herring, RED; redfish, COD; cod)

### 3.2.7 Comparison of toxicity as a function of taxa

A comparison of the range of toxicity measurement as a function of taxa again revealed some differences. The toxicity tests results were grouped by the following taxa; groundfish (pollock, cod, yellowtail flounder), molluscs (clam, mussel, scallop), crustacean (lobster, snow crab, Jonah crab, shrimp), pelagic (herring, fish meal, salmon, redfish), others (sea cucumber, algae) (Figure 3.9).

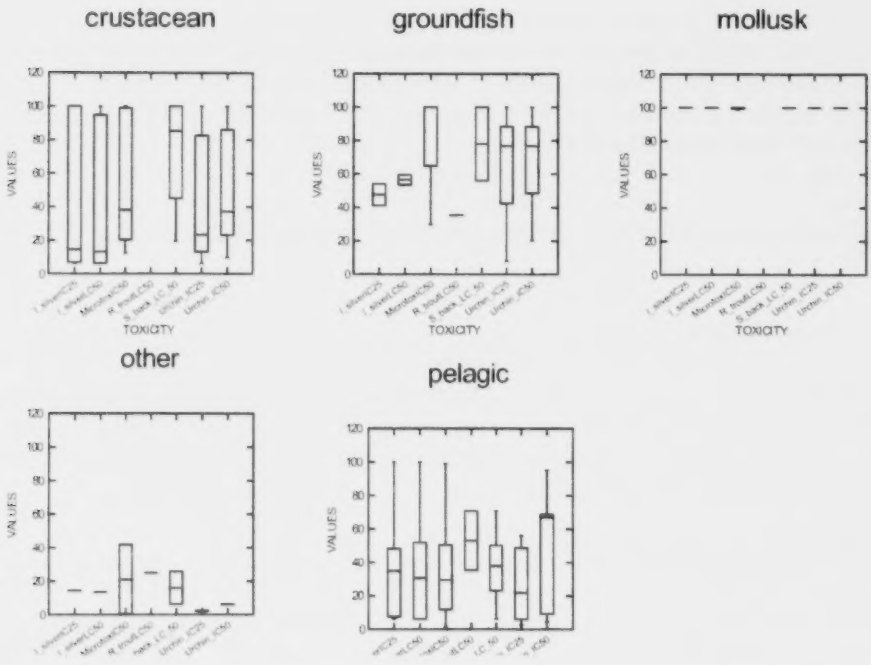


Figure 3. 9 Boxplots of toxicity testing results as a function of taxa (note that y axis is %dilution of effluent)

None of the mollusc processing effluent were toxic using any of the tests. Plants processing pelagic species and other species (sea cucumbers and algae) had the highest toxicity for Urchin$IC_{25}$ and Microtox™$IC_{50}$.

### 3.2.8 Correlations between toxicity test results

Pearson simple correlations between all of the toxicity tests were performed to determine the relationships between the test results for Microtox™ (*Vibrio fischeri*), Inland silversides, Threespine stickleback, sea urchin and rainbow trout. Bonferonni probabilities (significance level) of the correlations equal to or less than 0.05 indicated significant correlations. The correlation coefficients give a general idea of the trend (positive or negative) between two toxicity tests. There were three correlations between species which were statistically significant;

- Urchin $IC_{25}$ is correlated negatively to stickleback mortality (full strength effluent) ($p=0.003$, $n=12$)
- Inland silverside $IC_{25}$ are correlated negatively to stickleback mortality (full strength effluent) ($p=0.015$, $n=13$).

Overall, the lack of correlations between toxicity tests using different organisms indicates that a battery of tests is more indicative of the overall toxicity of the effluent than an individual toxicity test using a single organism. Strikingly there weren't any significant correlations between Microtox™ $IC_{50}$ and sea urchin fertilization $IC_{50}$ even if the graphical depictions of both tests in Figures 3.5 and 3.6 were very similar.

### 3.2.9 Regressions between effluent characteristics and toxicity tests

#### 3.2.9.1 Simple regressions

Simple regressions between all physical and chemical parameters and all toxicity test results were calculated. Statistically significant simple regressions between the effluent characteristics and toxicity tests results are described in (Table 3.4). Independent variables were log transformed to normalise the data.

Table 3.4 Simple Regression Results

| Dependant Variables | Independent Variable | N | Constant | Independent Variable | $R^2$ | F-Ratio | p |
|---|---|---|---|---|---|---|---|
| Urchin $IC_{25}$ | $log_{10}$ O&G | 19 | 86.91 | -33.66 | 0.559 | 21.57 | 0.000 |
| Urchin $IC_{25}$ | $log_{10}$ BOD | 19 | 146.04 | -42.23 | 0.442 | 13.49 | 0.002 |
| Urchin $IC_{50}$ | $Log_{10}$BOD | 19 | 152.34 | -41.03 | 0.448 | 13.8 | 0.002 |
| Microtox™ $IC_{50}$ | $log_{10}$ $SO_4$ | 25 | -25.9 | 28.8 | 0.356 | 12.71 | 0.002 |
| Microtox™ $IC_{50}$ | $Log_{10}$Ca | 25 | -9.8 | 29.8 | 0.273 | 8.63 | 0.007 |
| Microtox™ $IC_{50}$ | salinity | 25 | 25.9 | 2.07 | 0.354 | 12.57 | 0.002 |
| Stickleback $LC_{50}$ | $Log_{10}$ BOD | 17 | 140.2 | -34.3 | 0.324 | 7.181 | 0.017 |
| I. Silverside $IC_{25}$ | $log_{10}$ BOD | 19 | 150 | -45.1 | 0.356 | 9.404 | 0.007 |
| I. Silverside $LC_{50}$ | $log_{10}$ BOD | 19 | 149.76 | -45.09 | 0.361 | 9.588 | 0.007 |
| Microtox™ $IC_{50}$ | $log_{10}$ O&G | 22 | 78.42 | -20.94 | 0.199 | 4.97 | 0.037 |

Statistically significant simple regressions between effluent characteristics and toxicity explained between 16 and 56% of the variability of the dataset ($R^2$). The p values ranged from <0.001 to 0.037. From the coefficients listed above, an increase in oil and grease and BOD in a sample caused a statistically significant increase of the toxicity of the effluent to the sea urchin,

stickleback and inland silverside. The coefficients for sulphate, calcium and salinity level are positive which indicates that a decrease of toxicity to *Vibrio fischeri* occurs as concentrations of sulphate, calcium or salinity levels increases within an effluent sample. Correlation coefficient with Bonferonni probabilities were calculated for salinity, sulphate and calcium concentrations and showed that these three parameters are highly correlated ($p<0.001$). Therefore the three relationships between the toxicity to *V. fischeri* (Microtox™ $IC_{50}$) and the physical and chemical parameters are not surprising.

### 3.2.9.2 Principal Component Analysis

A principal component analysis is a tool used to reduce the number of variables. This is performed by combining numerous variables into factors which capture the essence of all the variables combined. The final number of factors depends on how little random variability can be explained by creating an extra factor.

A principal component analysis on effluent characteristics resulted in the data being reduced to two main factors (Figure 3.10). Factor 1 included the following variables; ammonia, sulphate, potassium, sodium, hardness, chloride, magnesium, calcium and could be loosely interpreted as major ions present in the effluent. Factor 2 included the following parameters; biological oxygen demand, oil and grease, total organic carbon, total phosphorus, total nitrogen, total suspended solids and was interpreted as a factor representing nutrients/ organic concentrations of the effluent. The percent of total variance explained by factors 1 and 2 were 47.5% and 28% respectively.

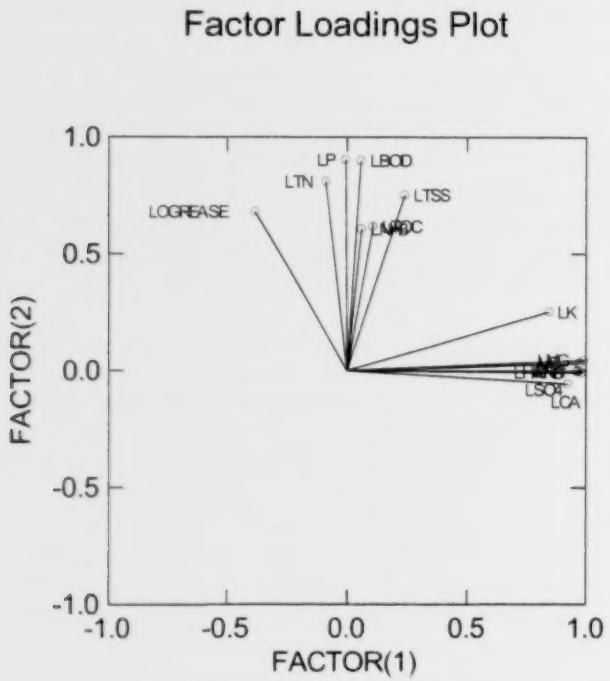


Figure 3. 10 Principal components of the physical and chemical parameters

Stepwise regressions were run on the untransformed toxicity results as a function of both

factors to detect if the factors were explaining the variability in the toxicity results. Six statistically significant regressions were present and are listed in Table 3.5.

Table 3. 5 Stepwise regression on the principal component factors

| Dependant Variables | Independent Variable | N | Coefficient | $R^2$ | F-Ratio | p |
|---|---|---|---|---|---|---|
| Urchin$IC_{25}$ | Constant<br>Factor 2 | 18 | 41.77<br>-24.71 | 0.384 | 9.96 | 0.006 |
| Urchin$IC_{50}$ | Constant<br>Factor 2 | 18 | 51.50<br>-22.86 | 0.343 | 8.35 | 0.011 |
| Microtox™$IC_{50}$ | Constant<br>Factor 1 | 21 | 53.67<br>21.90 | 0.301 | 8.59 | 0.009 |
| Sback $LC_{50}$ | Constant<br>Factor 2 | 14 | 64.58<br>-26.11 | 0.628 | 20.28 | 0.001 |
| Inland Silverside $IC_{25}$ | Constant<br>Factor 2 | 16 | 51.78<br>-26.31 | 0.485 | 13.16 | 0.003 |
| Inland Silverside $LC_{50}$ | Constant<br>Factor 2 | 16 | 50.75<br>-25.59 | 0.465 | 12.16 | 0.004 |

Results from Table 3.5 demonstrated the following;

- An increase in Factor 2 (nutrients/ organics) decreased the fertilization success of the sea urchin, survival of the three spine stickleback and growth of inland silverside. Similar relationships were also detected in simple regressions between oil and grease or BOD and three spine stickleback $LC_{50}$, inland silverside $IC_{25}$ and $LC_{50}$ and sea urchin $IC_{50}$ and $LC_{50}$ (Table 3.4).

- An increase in Factor 1 (major ions) is related to an increase in toxicity according to *Vibrio fischeri* (Microtox™ $IC_{50}$ test). Generally, effluents from plants using mostly freshwater compared to the plants discharging salty effluent (higher amounts of major ions in the effluent) had lower $IC_{50}$ values. These results from the principal component analysis are also explained by the two simple regressions between Microtox™ $IC_{50}$ and sulphate and calcium which yielded statistically significant relationships with positive coefficients for both independent variables (sulphate and calcium) (Table 3.4).

### 3.2.10 Comparison between plants processing same species (or taxa)

#### Herring

Two plants processing herring (Plant G and K) were sampled as well as one plant discharging a combination of herring and fish meal effluent (Plant N). Plants G and N had similar concentrations of the major ions in seawater (hardness, chloride, sulphate, magnesium, potassium, calcium sodium) compared to plant K which had concentrations an order of magnitude or two lower. The difference in concentration can be explained by the fact that plant K uses freshwater during the processing operations while the two other plants use saltwater or a combination of the two. Oil and grease concentrations varied between plants with a range from 33 to 297 mg/L with the highest concentrations found at the plants processing the highest

amounts of herring per day (Plants G and N). Total nitrogen concentrations also vary in the same way as oil and grease. Phosphorus concentrations (6.082 – 15.38 mg/L) were all within one order of magnitude from each other. BOD concentrations ranged from 145 to 654 mg/L while TSS concentrations ranged from 64 to 697 mg/L. Plant N had the highest concentrations of BOD and TSS while plant K had the lowest concentrations. This type of relationship is not found at all plants since the correlation between BOD and TSS is not statistically significant (Section 3.6.2)

No trends were discernable in the toxicity testing results. All of the individual plants had at least one of the lowest percent dilutions (most toxic effluent) in one or more of the toxicity tests. Effluent from Plant K had the most toxic effect to inland silverside $IC_{25}$ and $LC_{50}$ and *Vibrio fischeri* (Microtox™) $IC_{50}$, while effluent from Plant G had the most toxic effect on stickleback $LC_{50}$ and effluent from plant N had the most toxic effect on sea urchin $IC_{25}$ and $IC_{50}$ (Appendix B). It is interesting to note that plant K effluent had the most toxic effect to inland silversides compared to plant N and G but the effluent had the lowest concentration of TSS and BOD and low overall concentrations of chloride, sulphate, magnesium and potassium. This result leads us to hypothesize that characteristics of the effluent not evaluated as part of this study are causing toxicity to organisms.

**Lobster**

Four effluent streams from lobster processing plants were sampled as part of this study. Three of the effluent samples were collected during a period when the plants were processing lobster (Plant Id, D and Q) while the fourth sample (Plant Ic) only included the washdown period of a lobster processing line. Plant Ic, Id and Q had similar concentrations of the major ions in seawater (hardness, chloride, sulphate, magnesium, potassium, calcium sodium) compared to plant D which had concentrations an order of magnitude or two lower (Appendix B). The difference in concentration is probably because plant D uses freshwater during the processing operations while the three other plants use saltwater or a combination of the two during processing or washdown. While concentrations of BOD, TSS and oil and grease were low for the effluent from the washdown, Plant D had similar or lower concentrations of these parameters. Differences in BOD, TSS, TOC and TN varied greatly between plants processing lobster. This leads us to hypothesize that characteristic of the processing, such as methods of butchering and shucking of the meat are important determinants of certain parameters of the effluent.

Unfortunately equipment malfunction prevented obtaining enough sample of the processing of lobster at one of the effluent streams (the plant for which we obtained the washdown portion of the effluent). Effluent from the washdown was more toxic than processing effluent for the following toxicity tests; sea urchin fertilization $IC_{25}$, $IC_{50}$, % mortality at full strength- stickleback. The effluent from plant Q showed the highest toxicity to *Vibrio fischeri* (Microtox™) but at a level very similar as the effluent from the washdown of the equipment at plant Ic (Appendix B). The effluent at the third plant processing lobster (Plant D) also showed toxicity towards *Vibrio fischeri* but at half the concentrations measured for the two other effluent samples. It is recommended that we investigate further the usage and potential toxicity of chemicals (sanitizers, cleaners, disinfectants etc) discharged in effluent from fish processing washdown (See Section 4.8).

**Snow crab**

Three effluent streams from snow crab processing plants were sampled as part of this study. Plant F had significantly higher concentrations of TOC, phosphorus, oil and grease, BOD, TDS and TSS than plant E or plant V while plant V had the highest concentrations of total nitrogen and ammonia. Strangely plant E also had a higher concentration of mercury and the only measurable concentrations of alpha-benzenehexachloride, p,p DDE, dieldrin and total PCB in this study (discussed in section 4.1) However toxicity results for sea urchin $IC_{25}$ and $IC_{50}$ showed more toxic effects of the effluent from plant E while Microtox™ (*Vibrio fischeri*) $IC_{50}$ and % mortality of stickleback at full strength were both higher for the plant F. Both plants F and plant V had high toxicity ($LC_{50}$< 6.25%) to inland silversides while plant E had low toxicity to the inland silverside ($LC_{50}$=89.6%).

**Molluscs**

Although plants B, C and Ib processed different species (respectively clam, mussel and scallop), the results from our effluent characterisation revealed similar trends. Oil and grease concentrations in all three samples were all lower than 4mg/L while BOD concentrations range from 40 to 82 mg/L. Total suspended solids concentrations were not consistent since one of the samples (Plant C) had a concentration 10 times higher than the two others samples. The toxicity results were of particular importance since for all effluents there was no mortality of stickleback at full strength effluent and very little or no negative effect on urchin $IC_{25}$ and $IC_{50}$ and Microtox™ (*Vibrio fischeri*) $IC_{50}$ (greater than 99% for scallop). Based on these numbers, it appeared that mollusc processing did not represent a risk to the receiving environment. However effluent collected from the processing of other species of molluscs and maybe some replicates of some of the species we collected will be required to evaluate this conclusion. Some of the other potential species would include oysters and geoducks.

**Sea cucumbers**

Although this study only sampled one fish plant processing sea cucumbers, characteristics of the effluent from another plant processing sea cucumbers were obtained (R. Robichaud, pers. comm.) The data were obtained in 2002 and 2003 in a processing plant in New Brunswick.

Comparison of the data collected by Environment Canada in a New Brunswick sea cucumber facility in 2002 and 2003 reveals similar low $LC_{50}$ values for toxicity testing using fish species. Presently, the facility in New Brunswick uses a dissolved air floatation unit to treat processing effluent. The sample collected in our study in a Newfoundland facility in 2005 had the highest concentrations of BOD and total suspended solids as well as the lowest pH and $LC_{50}$ values (for a fish species) recorded to date for sea cucumbers processing effluents presented in Table 3.6. The sample collected in the Newfoundland facility also had the highest BOD concentration (4585mg/L) and most toxic effluent to stickleback ($LC_{50}$<6.25%) of all fish processing effluent collected during the study (Appendix B). Interestingly, the Microtox™ (*Vibrio fischeri*) $IC_{50}$ value ($IC_{50}$= 41.8%) of the effluent from the Newfoundland facility was in the middle of the range of values we obtained from all fish processing facility while the sea urchin $IC_{25}$ and $IC_{50}$ (2.37 and 6.33% respectively) were some of the more toxic effluent in comparison to all other fish processing plants. The wide variety of responses clearly indicates the need for a battery of toxicity tests.

Table 3. 6 Effluent characteristics for sea cucumbers processing plants

| **Parameters** | February 2002 NB plant* | March 2002 NB plant* | February 2003 NB plant* | September 2005 Nfld plant |
|---|---|---|---|---|
| Temperature (°C) | 5.1 | 4.7 | n/a | 11.5 |
| DO (mg/L) | 10.3 | 9.2 | n/a | 9.94 |
| pH | 7.76 | 7.59 | 7.29 | 5.98 |
| Salinity (‰) | 2 | 1 | n/a | 26 |
| Conductivity | 1893 | 2170 | n/a | 46200 |
| $NH_4$ (mg/L) | 1.6 | 0.403 | 5.720 | ($NH_3$) < 0.1 |
| BOD (mg/L) | 226 | 220 | 147 | 4585 |
| TSS (mg/L) | 70.3 | 193.8 | 46.2 | 693 |
| 96 hrs $LC_{50}$ (%) Rainbow trout | 8.84 | 9.47 | 61.6 | < 6.3** |
| *; Environment Canada , unpublished data **; Stickleback used since salinity > 10 ppt | | | | |

Part of the toxicity caused by the processing of sea cucumbers is probably caused by a holothurin (saponins); a toxin which the sea cucumbers produces. The toxin is located in the body wall of the sea cucumbers and affects fish by entering through the gills (Halstead 1988). It would appear that the dissolved air flotation unit is effective at reducing the BOD and TSS but does not substantially reduce toxicity.

**Salmon**

To date, we have been permitted to collect a single sample at a plant (Plant H) processing farmed Atlantic salmon fillet in the Atlantic Provinces (Table 3.7). The butchering process was not performed on the premises since the salmon arrive at the plant in fillet and are further transformed on-site. Three more plants processing (and butchering) farmed Atlantic salmon were sampled in British Columbia in the winter of 2007 (Table 3.7). Jamieson *et al* (2006) sampled effluent from a plant processing (and butchering) salmon in Newfoundland (Table 3.7). A study conducted for Environment Canada in British Columbia in 2005 sampled effluent at two farmed Atlantic salmon processing plants (Environment Canada 2005) (Table 3.7). Interestingly, BOD and TSS values had variable ranges of values with the highest BOD measured in British Columbia in 2005 and the highest TSS concentration detected at plant S. The pH measured at plant H (pH= 10.63) was the highest of all the effluent samples collected during this study and higher than the pH measured at the plant sampled by Jamieson *et al.* (pH=6.39) and Environment Canada (2005). It is hypothesized that the elevated pH measured at plant H is due in part to certain cleaning chemicals in use at the plant and released in the effluent. One of these chemicals is a degreaser which has a pH of12-13. The ammonia concentrations were two orders of magnitude higher for the plants in British Columbia compared to plant H. This is partly explained by the fact that butchering was occurring at the plant in BC and not at the plant visited during this study. Oil and grease concentrations for the effluent from plant H was measured as 81mg/L which is approximately 5 times higher than the results for the plants in British Columbia. This might indicate that the oil and grease concentrations are not related to the butchering process but rather to the further processing (value added transformation) occurring at plant H which was sampled in our study. Toxicity to *Vibrio fischeri* (Microtox™) was similar in our study when compared to the results of Jamieson *et al.* (2006) who measured levels of Microtox $IC_{50}$ of 7.85% (Table 3.7). The effluent from the BC plants had similar toxic effects to the stickleback while the lowest toxicity was recorded for the effluent from plant H (Table 3.7).

Table 3.7 Effluent characteristics for farmed salmon processing plants

| Parameters | Plant H | Plant S | Plant T | Plant U | NFLD plant* | BC plants average** |
|---|---|---|---|---|---|---|
| Temperature (°C) | 8.7 | 7 | 6.2 | 7.2 | n/a | 5.03 |
| DO (mg/L) | 12.52 | 8.5 | 8 | 8.25 | n/a | 6.1 |
| pH | 10.63 | 6.98 | 6.55 | 6.97 | 6.39 | 8.43 |
| $NH_3$ (mg/L) | 0.26 | 3.33 | 17.8 | 8.82 | 1.82 | 21 |
| BOD (mg/L) | 115 | 101 | 137 | 670 | 268 | 905 |
| TSS (mg/L) | 85 | 1280 | 123 | 514 | 120.1 | 203 |
| Microtox $IC_{50}$ (%) | 1.43 | 25.5 | 33.6 | 13.7 | 7.85 | n/a |
| 96 hrs $LC_{50}$ (%)*** | 70.7 | <6.25 | 17.7 | 28.7 | n/a | 17**** |
| *Jamieson *et al.* 2006, **Environment Canada 2005, *** stickleback, **** fish species undefined | | | | | | |

**Yellowtail flounder**

Effluents from the plant processing yellowtail flounder (Plant O) were analysed as part of our study and also as part of the study by Jamieson *et al.* 2006. The following test compared the two dataset. Samples collected in our study had a BOD of 2415mg/L, TSS of 549mg/L and ammonia equal to 0.68mg/L. Concentrations of BOD and TSS were one order of magnitude higher in our study than the level measured by Jamieson *et al.* (2006) while ammonia concentrations were almost an order of magnitude higher in the sample by Jamieson et al. (2006). Our study showed that the effluent was not toxic to *Vibrio fischeri* (Microtox™) while the $IC_{50}$ from Jamieson *et al.* (2006) was 21.18%. BOD concentrations from our study was equal to 2415mg/L (Jamieson measured 236mg/L) and one of the highest concentrations measured in all fish processing plants sampled in our study. These results and the results from the simple regressions (Section 3.2.9.1) seem to indicate that BOD concentrations were not good predictors of toxicity to *Vibrio fischeri* (Microtox™). However the sample collected by Environment Canada showed toxicity to both sea urchin $IC_{25}$ and stickleback $LC_{50}$. Variable toxicity responses using different species indicate the usefulness of batteries of toxicity tests are required when characterising effluents and these two studies conducted at the sample plant suggest great variability over time at a single plant.

## 3.3 Comparison by Processing Categories

Comparison of the characterization and toxicity of fish plant effluent data was also approached by categorizing the types of processing occurring in the fish plants. The types of processing followed the category approach from Beaudin (2001). Beaudin (2001) states that the fish processing sectors in eastern Canada can be divided in three classes of industrial processing determined by the level of product processing.

According to Beaudin (2001);

- primary processing refers to the initial operation (basic packaging of a fresh product).
- Secondary processing applies to a class of products that have undergone further processing (raw material has been significantly processed for the purpose of preservation and/or presentation.

- Tertiary processing comprises products that will by processed by means of various technical and technological processes that are more elaborate that those of the first two phase.

The three levels of processing were defined by national and international standardization entities (Beaudin 2001). Table 3.8, lists the type of processing and category of processing according to the characteristics in Beaudin 2001 of all the plants who participated in this study.

Table 3. 8 Category of processing, 1 indicating a primary processing, 2 indicating a secondary processing and 3 indicating a tertiary processing.

| Organisms Processed | Category # | Type of processing |
|---|---|---|
| Lobster | 1 | Raw and frozen; shell off |
| Lobster | 3 | Cooked and raw. Cooked; breaking, cooking, packing and freezing |
| Lobster | 3 | Fresh (live and cooked), frozen (split), raw claws and minced meat |
| Snow Crab | 1 | Fresh and frozen; Raw and cooked |
| Snow Crab | 1 | Butchering and processing of raw and cooked crab. Does not normally extract meat. Products are normally in round or in section. |
| Clam | 1 | Fresh or chilled (in shell or meat) |
| Mussel | 1 | Fresh or chilled (in shell) |
| Pollock | 2 | Fillets (dried and salted) |
| Herring | 3 | Fresh and frozen; canned, dressed, fillet and smoked. |
| Herring | 3 | Fillets and whole, cooked and cutting |
| Jonah Crab | 3 | Crab claws; shell on, cooked and frozen. Pasteurized crab meat (extraction, cooking) |
| Scallop | 1 | Washed and graded (raw and frozen). Shucked at sea |
| Algae | 3 | Cooking, Drying, grinding, extracts. |
| Salmon | 2 | Oven and cold smoked, brining. |
| Salmon | 1 | Butchering and processing of raw salmon |
| Sea cucumber | 1 | Fresh – meat (body walls) |
| Yellowtail flounder | 3 | Fillets, fresh and frozen (stuffed and breaded fillets) |
| Herring + Fish meal | 3 | Fillets (fresh, frozen, marinated, salted). Fishmeal |
| Cod | 3 | Frozen fillets received at plant. Breaded and/or battered cod strips (some cutting) |
| Shrimp | 3 | Fresh and frozen; Cooked and peeled |
| Redfish | 1 | Fresh, dressed, fillets |

Figures 3.11 show how the log transformed concentrations of various parameters of the fish plant effluent varies with the category of processing depicted in Table 3.8. Only figures which showed differences between categories are presented above. Unfortunately only two effluent are from plants categorized as a category # 2, therefore the comparison to category #2 is difficult to interpret. However the comparison between categories 1 and 3 are numerous and show higher concentrations of oil and grease, total nitrogen, total organic carbon, total phosphorus and BOD for category 3. Concentrations of ammonia are similar in all three categories.

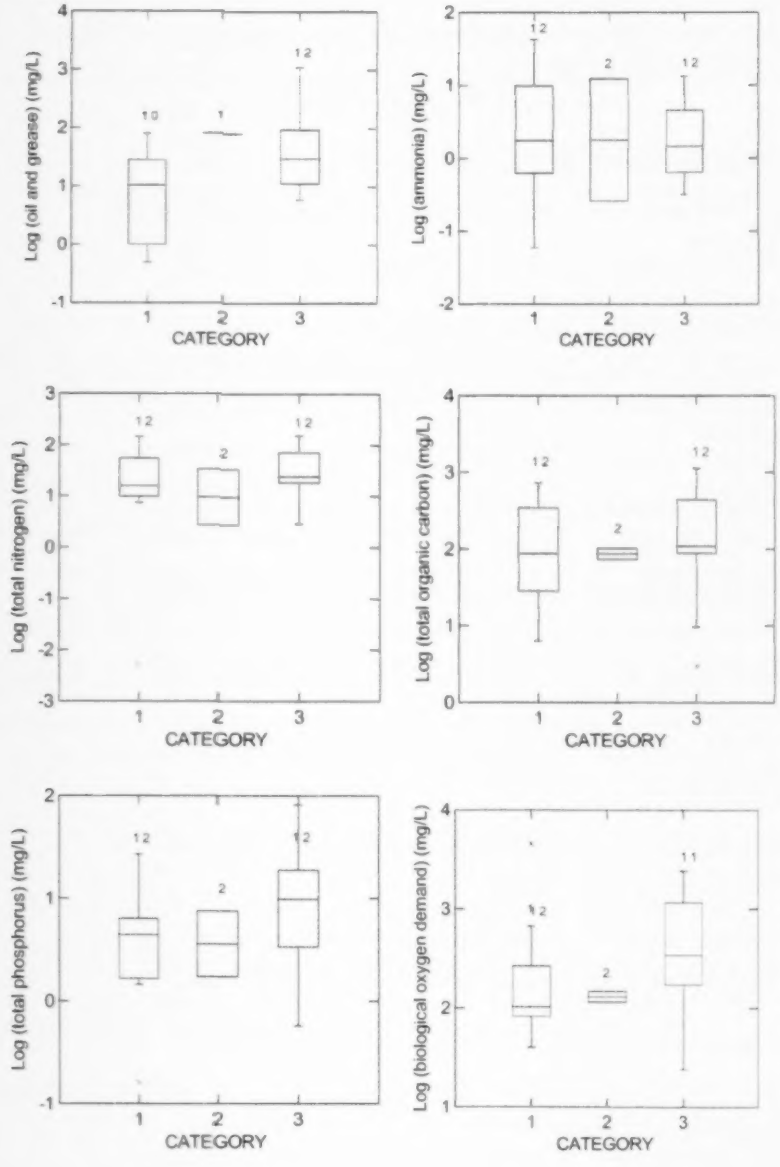


Figure 3. 11 Log transformed concentrations of physical and chemical parameters as a function of category of processing. (Note number of observations above box plots)

Another interesting comparison can be done between the processing categories when

combining the toxicity testing results per category. (Figure 3.12). Number of individual tests results for each Boxplots are 53 for category 1, 12 for category 2 and 61 for category 3. The figure below clearly shows an increase in toxicity as you progress from a category 1 effluent to a category 3 effluent. However there are some individual test results of category 1 effluent that showed a highly toxic effluent that are in the upper 75% of the results in category 3.

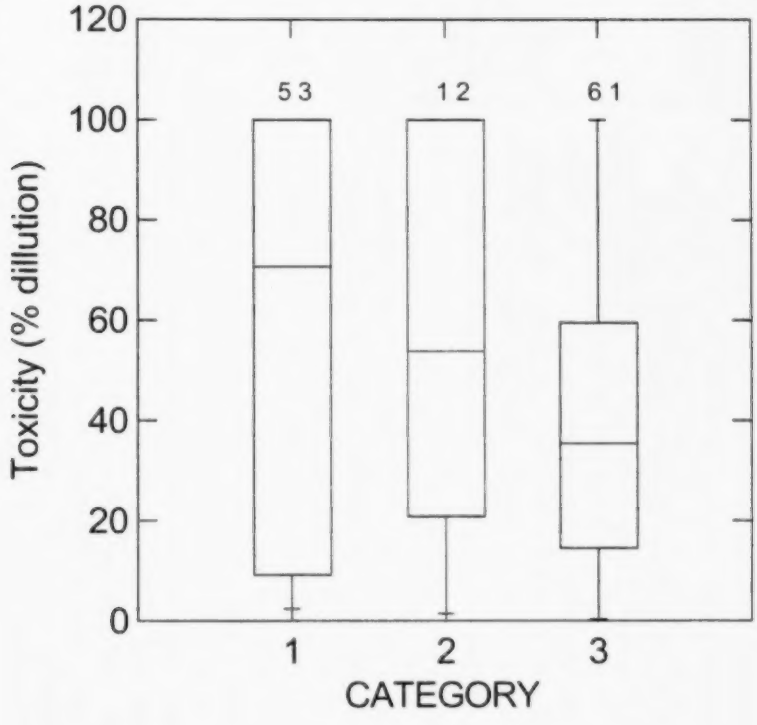


Figure 3. 12 Percent effluent concentrations of all toxicity tests as a function of category of processing. (Note number of observations above box plots)

### 3.4 Results from Questionnaires

Questionnaires were filled in with the assistance of plant operators and mangers for each plant visited in 2004 and 2005. Table 3.9 below presents a summary of the responses of the questionnaires.

Table 3.9 Summary of results from questionnaire

| Plant ID* | Type and volume of fish processed | Water used in plant | Active ingredients present in products used for cleaning/ sanitizing | Volume of effluent discharge** | Distance from shore to outfall |
|---|---|---|---|---|---|
| G | Herring 480-500 tonnes(t)/day | Saltwater | Nitric acid, phosphoric acid, alcohols C12-15 ethoxylated, potassium hydroxide, triphosphoric acid, pentasodium salt, amines coco akyldimehtyl n-oxide, potassium hypochlorite, xylenesulfonic acid, sodium salt, sodium hydroxide, d-gluconic acid monosodium salt, oxirane methyl polymer with oxirane, mono(hydrogen sulphate) decyl ether sodium salt, oxirane methyl polymer with oxirane, mono(hydrogen sulphate) dodecyl ether sodium salt, butenoic acid octenyl disodium salt. | 600gallons/ minute (gpm)** | 76m |
| H | Salmon 18t/month | Freshwater | N-alkyl benzalkonium chloride, ethanol, polyethoxy polypropoxy polyethoxy ethanol – iodine complex, nonylphenoxypoly (ethyleneoxy) ethanol – iodine complex, propylene glycolmethyl ether, sodium hydroxide, sodium nitrite. | 80000 Gallons/ month** | Municipal treatment |
| Ia | Jonah crab 9t/day | Saltwater | Ethanol, alkyl dimethyl benzyl ammonium chlorides, glutaric dialdehyde, sodium hydroxide, linear alkyl benzene sulphonic acid, citric acid, propylene glycol, Nitric acid, phosphoric acid, hydrofluoric acid, sulphuric acid, lauryldimethylamine oxide, sodium metalsilicate, alkyl dimethyl ethyl benzyl ammonium chlorides, ethylene glycol monobutyl ether, trisodium phosphate, linear alkyl benzene sulphonic acid, sodium carbonate, potassium hydroxide, sodium hypochlorite, sodium dodecylbenzene sulfonate, tetra sodium ethylenediamaine tetraacetate, | 527gpm** | 0m |
| Ib | Scallop | | | | |
| Ic | Lobster 6.8 t/day | | | | |
| J | Algae 22.7 t/day | Freshwater | Potassium hydroxide, sodium hydroxide, sodium hypochlorite, sodium lauryal sulfate, polyacrylic acid solution, ethanol, alkyl dimethyl benzyl ammonium chlorides, dialkyl dimethyl ammonium chlorides, phosphoric acid, nonyl phenol ethoxylate, diethylene glycol methyl ether, alcohol alkoxylate, sodium metasilicate | 1250000 gallons/ month** | Municipal treatment |
| K | Herring 9.5 t/day | Freshwater | n/a | 333000 gallons/ month** | 0m |
| L | Redfish 18 t/day | Saltwater | Potassium hydroxide, lauryldemthylamine oxide, sodium hypochlorite, alkyl dimethyl benzyl ammonium chlorides | 300gpm** | 0m |

| Plant ID* | Type and volume of fish processed | Water used in plant | Active ingredients present in products used for cleaning/ sanitizing | Volume of effluent discharge** | Distance from shore to outfall |
|---|---|---|---|---|---|
| M | Cod<br>6.8 t/day | Saltwater and freshwater | Ethylene glycol monobutyl ether, sodium hydroxide, sodium dodecylbenzene sulfonate, tetrasodium ethylenediamine tetraacetate, Ethanol, Alkyl dimethyl benzyl ammonium chlorides, Potassium hydroxide, Sodium metasilicate, Sodium hypochlorite, Diethylene glycol monobutyl ether, Monoethanolamine Sodium dodecylbenzene sulfonate, D-limonene, Heavy aromatic naphta, Tetrapotassium pyrophosphate, Blend of isobutane and propane, Blend of isobutane and propane | 250gpm** | 0m |
| N | Herring/fish meal<br>100 t/day (herring)<br>7 t/day (meal) | Saltwater | Potassium hydroxide, lauryldemthylamine oxide, sodium hypochlorite, alkyl dimethyl benzyl ammonium chlorides, Sodium metasilicate, Alkyl dimethyl benzyl ammonium chlorides, Alkyl Dimethyl Ethyl Benzyl Ammonium Chlorides, Sodium carbonate, Sodium metasilicate | 2000gpm** | 10m |
| O | Yellowtail flounder<br>50 t/day | Saltwater | Sodium xylene sulphonate, Potassium hydroxide, Alkyl dimethylamine oxide, Sulfonic acid, petroleum, sodium salts, Sodium hypochlorite, Sodium tripolyphosphate, Nitric acid, Phosphoric acid, Ethanol, Alkyl dimethyl benzyl ammonium chlorides | 2100gpm** | 20m |
| P | s. cucumber<br>9 t/day | Saltwater | n/a | 6 and 8 inch line | 0m |
| Q | Lobster<br>22.7 t/day | Saltwater | Sodium metasilicate, Sodium hypochlorite, Potassium hydroxide, Lauryldimethylamine oxide, Phosphoric acid, Hydrofluoric acid, Lauryldimethylamine oxide, Sodium chlorite, Sodium metasilicate, Alkyl Dimethyl Ethyl Benzyl Ammonium Chlorides, Alkyl dimethyl benzyl ammonium chlorides, Tetrasodium Ethylenediamine tetraacetate, Propylene glycol, Sodium hydroxide | 150gpm | 100m |
| R | Shrimp<br>68 t/day | Saltwater | n/a | 450gpm** | 200m |
| S | Atlantic salmon (63t/day) | Saltwater | Alkyl dimethyl benzyl ammonium chloride, alkyl dimethyl ethylbenzyl ammonium chloride, Sodium hypochlorite, Sodium hydroxide | 2900gallons/hour | 20m |

| Plant ID* | Type and volume of fish processed | Water used in plant | Active ingredients present in products used for cleaning/ sanitizing | Volume of effluent discharge** | Distance from shore to outfall |
|---|---|---|---|---|---|
| T | Atlantic salmon (20000pieces/ day) | Saltwater and freshwater | n-alkyl, dimethy benzyl ammonium chloride, Ethylene glycol monobutylether, Sodium metasilicate, Potassium hydroxide, Triethanolamine | 91000gallons/ day | 30m |
| U | Atlantic salmon 90t/day | Freshwater | n-alkyl, dimethy benzyl ammonium chloride, Ethylene glycol monobutylether, Sodium metasilicate, Potassium hydroxide, Triethanolamine | 91941gallons/ day | 310m |
| V | Snow crab 13.6 t/day | Saltwater | Propylene glycol, Potassium hydroxide, Lauryldimethylamine oxide, Sodium hypochlorite, Alkyl dimethyl benzyl ammonium chlorides, Sodium ethylenediaminetetraacetate, Alkyl dimethyl benzyl ammonium chloride, alkyl dimethyl ethylbenzyl ammonium chloride | n/a | 0m |

*survey with plant managers only started in 2004 and therefore there is no data for the first six plants sampled.
** Discharge volume is unknown; the volume presented is the water consumption

# 4.0 DISCUSSION

## 4.1 Effluent Characterization

### 4.1.1 Field Measurement

Chlorine is used to disinfect water used in fish processing plants and it has been reported that excessive chlorination may be a problem (Novatec 1994). High chlorine concentrations can be acutely toxic and may also cause genetic damage at low concentrations (Payne *et al.* 1980). Environment Canada has established a desirable concentration for chlorine of 0.02 mg/L in the effluent released to surface water (Environment Canada 2004). That limit only applies if the annual daily average of effluent volume met or exceeded the threshold of 5 000 $m^3$/day. Although there is no precise information on effluent discharge volume from fish processing plants in Canada, the reported effluent volume from our study was 15 to 3800$m^3$/day. Therefore this notice would not apply to any of the plants we sampled. Measurement concentrations of total residual chlorine from our study ranged from 0.0 to 0.5 mg/L, however those results were obtained using paper test strips which are not very precise.

Correlation coefficient with Bonferonni probabilities were calculated between salinity, sulphate and calcium concentrations and showed that these three parameters are highly correlated ($p<0.001$). Therefore the three relationships between the toxicity to *V. fischeri* (Microtox $IC_{50}$) (Table 3.4) and salinity, sulphate and calcium concentrations were expected since all three parameters are correlated. There are at least two possible reasons for these relationships;

1) Toxicants are more soluble in freshwater than in seawater causing a more toxic response to *V. fischeri* in low salinity levels samples (K. Doe pers. comm.)
2) Another possibility which could explain the results is that the dissolved salts in seawater provide some kind of protection which has been previously detected in studies where metals were the toxicant (K. Doe pers. comm.).

In any case, the response is not due to low salinity stress since salinity of the effluent is adjusted to suit the requirement of the marine organism (*V. fischeri*) before the start of the Microtox™ test (Environment Canada 1992a).

### 4.1.2 Conventional Parameters

Ammonia is present in the blood and slime of most fish and shellfish species as well as used as a disinfecting agent in some plants (Novatec 1994, AMEC 2003). The ecological impact of ammonia in aquatic ecosystems is likely to occur through chronic toxicity to fish and benthic invertebrate populations as a result of reduced reproductive capacity and reduced growth of young (Environment Canada 2001). These are subtle impacts that will likely not be noticed for some distance below an outfall. The zone of impact varies greatly with discharge conditions, river dispersion rates, temperature and pH (Environment Canada 2001). The protection of aquatic life is ensured by achieving an effluent quality where the concentration of ammonia being discharged to the receiving environment is not acutely lethal (Environment Canada 2001). Degree of ammonia toxicity is dependant on total ammonia concentration and pH (Environment Canada 2001). The pH level determines what proportion of the total ammonia present is in its

toxic unionized form (NovaTec 1994). Maximum allowable ammonia concentration (y) at the measured pH of the effluent can be calculated using the following equation:

$$y = 306132466.34 \times (2.7183^{(-2.0437 \times pH)})$$

Ammonia concentrations in the effluent samples ranged from 0.06 to 42.67mg/L. Ammonia concentrations in fish processing effluent have historically ranged from 1.8 to 250mg/L (Table 4.1). In comparison, ammonia concentrations in effluent from potato and meat rendering plants were 2 and 8 mg/L respectively. The maximum allowable concentration (calculated using the formula above) was exceeded only once in all the samples collected by Environment Canada. Although the concentration of ammonia in the effluent discharged from plant H was low ($NH_3$=0.263mg/L), the high pH (10.63) associated with the effluent brought the level of ammonia to a toxic level. However, the effluent from this particular plant is sent to a municipal effluent system before discharge to the environment.

Novatec (1994) stated that nitrogen measured in effluent streams was mostly in the form of ammonia since the source of ammonia was usually from slime and blood (NovaTec 1994). Therefore the results in Figure 4.1 which shows that the linear relationship between total nitrogen and ammonia (both log transformed) was expected. The log transformed data for nitrate (LNO3) did not follow any trends and was mostly under the detection limit of the laboratory.

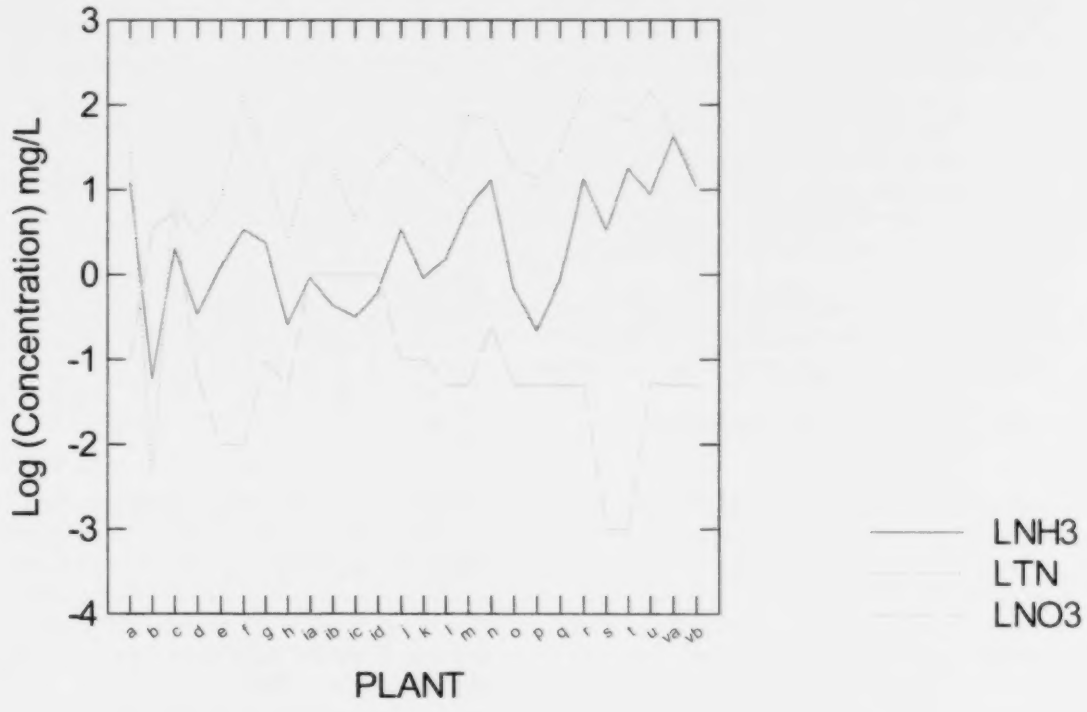


Figure 4. 1 Scatterplot of total nitrogen (TN), ammonia (NH3) and nitrate (NO3) in the effluent samples.

Water quality guidelines help to protect all aquatic organisms that live by establishing acceptable concentrations for substances or conditions that affect water quality. The Canadian Water Quality Guidelines are based on toxicity data for the most sensitive species of organisms found in Canadian waters and act as science-based benchmarks for the protection of all of the aquatic life species in Canada, at all times. Separate guidelines for freshwater and marine water organisms have been established. Unfortunately there were only three Canadian Water Quality Guideline for substances measured in this study. The guideline for pH and mercury was exceeded in the majority of effluent samples. Mercury concentrations are discussed in section 4.1.5.

#### 4.1.2.1 Calculation of loadings

A summary of concentrations of various parameters typically measured in fish processing effluent, as reported in the literature, is presented in Table 4.1. Variations in species processed, processing equipment, chemicals used in the plant and water source make it difficult to define the characteristics of a general effluent from fish processing. Therefore the data in Table 4.6 was further sub-divided by species processed or type of processing (Appendix C). Overall, high BOD, oil and grease, TSS and nitrogen can be expected from fish processing plants. The results from our study fall within the ranges published in the literature.

Table 4. 1 Range of fish processing effluent characteristics

| Parameter | Our Study | Historical Range (Appendix C) |
|---|---|---|
| Biological oxygen demand | 24 - 4585 | 1.54 - 277000 |
| Chemical oxygen demand | n/a | 46 - 342200 |
| Total Suspended Solids | 9.5 - 1280 | 22 - 20000 |
| Oil and Grease | 1 - 1117 | 10 - 5000 |
| Total Kjeldahl Nitrogen | 2.72 – 154.3 | 18 - 6414 |
| Ammonia | 0.06 42.67 | 1.8 - 250 |
| Chloride | 32.4 - 18558 | 20 - 15820 |
| Total Phosphorus | 0.162 – 81.8 | 4.78 - 93 |
| pH | 5.77 – 10.63 | 5.45 - 8.1 |
| Phosphate | n/a | 0.005 - 220 |
| Sulphate | 4.7 - 2444 | 0.55 - 2040 |
| Nitrate | <0.002 – 5.84 | 0.082 - 2613 |

Unfortunately the dataset in Appendix C is not completely comparable to our dataset since, in most cases, the effluent characteristics are from completely different species. Where we could make comparison, the effluents characteristics of out study fell within the range of measurements from other studies

Calculations of loadings of certain parameters, such as BOD, TSS and oil and grease are mandatory for fish processors in the United States under the National Pollutant Discharge Elimination system permit. The EPA effluent limitations establish the quantity of pollutants or pollutant properties which may be discharged to the environment. These limitations are based on the control of the discharge of pollutants which reflect the greatest degree of effluent reduction which the Administrator determines to be achievable through application of the best available demonstrated control technology, processes, operating methods, or other alternatives, including, where practicable, a standard permitting no discharge of pollutants (EPA 1974). The

effluent limitations are separated by species processed. The EPA effluent limitations used in the section are for new sources. Only plants for which there was sufficient information collected to calculate loadings are compared to the EPA effluent limitations. Furthermore, there are some species for which no EPA effluent limitations exist. Results from the calculations of loading and comparison to EPA effluent limitations are presented separately for the following groupings; molluscs and crustaceans, finfish and groundfish. This type of measurement does not account for the capacity of the receiving environment to assimilate effluents.

For all groupings, half of the loadings calculated were higher than the EPA effluent limitations. Some species such as scallop and cod had all effluent characteristics below the effluent limitations while the processing of other species created effluent where only one or two parameters were higher than the limitations. Calculations of loadings for individual species are described in Appendix D.

**Molluscs and Crustaceans**

There are no EPA guidelines regarding the discharge of lobster processing effluent. The output of BOD/ tonne of lobster processed was above the average of daily values for 30 consecutive days for both blue crab and Dungeness/Tanner crab effluent EPA limitations limits.

Unfortunately there is no EPA effluent limitation guidelines for Jonah crab but there are some for Dungeness and Tanner crab (Table 4.2). All of the parameters exceeded the monthly average while oil and grease and total suspended solids also exceeded the daily maximum. Comparable concentrations of BOD and oil and grease have been reported by Québec crab processors (no specific species was targeted) (Ministère de l'Environnement et de la Faune du Québec 1995). Loading concentrations of BOD for Québec processors have been calculated between 8 to 30kg/ tonne while oil and grease concentrations were found to be between 0.8 to 5 kg/tonne (Ministère de l'Environnement et de la Faune du Québec 1995). Concentrations of BOD and oil and grease from Québec processors of crab were higher in comparison to the results from this study.

Both oil and grease and total suspended solids values were well under the EPA effluent limitation guidelines for scallop processing (Table 4.2). This is not surprising since the scallops were shucked and then frozen at sea. Once at the plant, the scallops are not cooked but they are stored, checked and glazed for shipments to various clients.

Although the total output per day of BOD and TSS for shrimp processing seemed high (over 100 kg), the amount of shrimp processed per day (34000kg) reduced the outputs to level which were below the EPA guidelines for Northern shrimp (Table 4.2). Concentrations of BOD and oil and grease have also been reported by Québec shrimp processors and have been calculated between 60 to 120 kg/ tonne while oil and grease concentrations were found to be between 4.5 to 20kg/tonne (Ministère de l'Environnement et de la Faune du Québec 1995). Concentrations of BOD and oil and grease from Québec processors of shrimp were both elevated in comparison to the results from this study. The results from this study were based on only one processor which used a dissolved air flotation (DAF) unit to reduce organic loading of its effluent prior to discharge into the receiving environment. The effluent sample tested as part of this study was collected after the effluent was treated by the DAF unit.

Table 4. 2 Effluent loadings and limitations for Molluscs and Crustaceans

| Plant ID | Species | Parameter | Effluent loading (kg/tonne)* | EPA effluent limitations (kg/tonne) Month avg (daily max) |
|---|---|---|---|---|
| Id | Lobster | O & G | 0.64 | n/a |
| | | BOD | 9.5 | n/a |
| | | TSS | 3.71 | n/a |
| Ia | Jonah crab EPA; Tanner and Dungeness crab | O & G | **0.35** | 0.1 (0.25) |
| | | BOD | **5.7** | 4.1 (10) |
| | | TSS | **6.3** | 0.69 (1.70) |
| Ib | Scallop | O & G | 0.00071 | 0.23 (7.3) |
| | | BOD | 0.11 | n/a |
| | | TSS | 0.079 | 1.4 (5.7) |
| R | Shrimp EPA; northern shrimp | O & G | 2.51 | 5.7 (14) |
| | | BOD | 55.75 | 62 (155) |
| | | TSS | 12.96 | 15 (38) |

*Assumption for calculations are listed in Appendix D

**Groundfish**

The concentrations of oil and grease and total suspended solids for the cod processing effluent were below the EPA limitations for mechanized non Alaskan bottomfish processing (Table 4.3). Concentrations of BOD were not measured for the cod processing effluent due to technical difficulties.

The oil and grease output at the plant processing redfish was higher than both the monthly and daily maximum EPA guidelines while the BOD level was just below the limitations for the monthly average (Table 4.3). The TSS level at the redfish processing plants was well below the EPA effluent limitations.

The effluent from the yellowtail flounder processing showed a BOD output which was higher than both the monthly and daily maximum guidelines while the TSS level was just below the monthly average but higher than the daily maximum (Table 4.3). Oil and grease level was below the EPA effluent limitations. Comparable concentrations of BOD and oil and grease have been reported by Québec groundfish processors (no specific species was targeted). Loading concentrations of BOD for Québec processors have been calculated between 3 to 21kg/ tonne while oil and grease concentrations were found to be between 0.2 to 5 kg/tonne (Ministère de l'Environnement et de la Faune du Québec 1995). Concentrations of BOD and oil and grease from Québec processors of groundfish were in the same range of values in comparison to the results from this study.

Table 4. 3 Effluent loadings and limitations for Groundfish

| Plant ID | Species | Parameter | Effluent loading (kg/tonne)* | EPA effluent limitations (kg/tonne) Month avg (daily max) |
|---|---|---|---|---|
| M | Cod EPA; Non Alaskan bottom fish | O & G | 0.2 | 0.47 (1.2) |
| | | BOD | | |
| | | TSS | 2.56 | 2.9 (5.3) |
| L | Redfish EPA; Non Alaskan bottom fish | O & G | **5.82** | 0.47 (1.2) |
| | | BOD | 7.11 | 7.5 (13) |
| | | TSS | 1.67 | 2.9 (5.3) |
| O | Yellowtail flounder EPA; Non Alaskan bottom fish | O & G | 0.32 | 0.47 (1.2) |
| | | BOD | **18.42** | 7.5 (13) |
| | | TSS | **4.188** | 2.9 (5.3) |

* Assumption for calculations are listed in Appendix D

**Finfish**

For the salmon, the concentration of oil and grease, BOD and TSS concentrations were well below the EPA limitations (Table 4.4). Interestingly the concentrations of BOD and TSS as effluent loading (kg/tonnes of salmon) were similar in plants that butchered the salmon to the plant in which no butchering was occurring (Plant H).

Of all three parameters for which the EPA has limitations, only oil and grease exceeded the monthly average limit (Table 4.4) for herring at plants G and K.

Although the total output per day of BOD and total suspended solids at plant N seemed high (over 100 kg), the amount of fish processed per day (100 tonnes) reduced the outputs to level which were below the EPA guidelines. There is also a guideline for fish meal plant but the outfall sampled was used for both the herring processing and fish meal plant effluent. Furthermore, an enhanced effluent treatment was in place in the fish meal plant.

Table 4. 4 Effluent loadings and limitations for Finfish

| Plant ID | Species | Parameter | Effluent loading (kg/tonne)* | EPA effluent limitations (kg/tonne) Month avg (daily max) |
|---|---|---|---|---|
| H | Atlantic Salmon** EPA; West Coast salmon butchering | O & G | 1.33 | 1.5 (4.2) |
| | | BOD | 1.89 | 38 (62) |
| | | TSS | 1.41 | 7.6 (13) |
| S | Atlantic Salmon EPA; West Coast salmon butchering | O & G | n/a | 1.5 (4.2) |
| | | BOD | 0.14 | 38 (62) |
| | | TSS | 1.78 | 7.6 (13) |
| U | Atlantic Salmon EPA; West Coast salmon butchering | O & G | 0.06 | 1.5 (4.2) |
| | | BOD | 2.59 | 38 (62) |
| | | TSS | 1.98 | 7.6 (13) |
| G | Herring EPA; non-Alaskan | O & G | **1.29** | 1.1 (2.9) |
| | | BOD | 1.49 | 15 (16) |

| Plant ID | Species | Parameter | Effluent loading (kg/tonne)* | EPA effluent limitations (kg/tonne) Month avg (daily max) |
|---|---|---|---|---|
| | herring fillet | TSS | 1.51 | 5.2 (7) |
| K | Herring EPA; non-Alaskan herring fillet | O & G | **1.91** | 1.1 (2.9) |
| | | BOD | 8.42 | 15 (16) |
| | | TSS | 3.71 | 5.2 (7) |
| N | Herring/Fish meal EPA; non-Alaskan herring fillet | O & G | 0.212 | 1.1 (2.9) |
| | | BOD | 1.43 | 15 (16) |
| | | TSS | 1.52 | 5.2 (7) |

* Assumption for calculations are listed in Appendix D
** No butchering at this processing facility

### 4.1.3 Persistent Organic Pollutants

PCBs were detected in only one sample (Plant F, which process snow crab) of the first fourteen samples analysed and therefore were not analysed in subsequent samples. The concentration of PCBs in effluent from Plant F was 233 ηg/L which is within the range of previously detected concentrations from fish processing effluent from groundfish and finfish processing effluent (Carawan *et al.* 1979 and Ernst *et al.* 1982) and above the EPA guideline. PCBs are stable and found in sediment, water and tissue. They absorb into the fatty tissues of organism and biomagnify as they move up the food chain. Historically, the highest concentrations of PCBs have been detected in the hepatopancreas of crab and in the head, gut, and liver of fish (Eisler 1986). Unfortunately, the origin of the snow crab processed on the day of sampling is unknown. This information could have explained the sources of the PCBs in the effluent since there are known hotspots of PCB contamination in Atlantic Canada (Irving whale barge site for example) (EC 1999). A previous study also suggested that the PCBs in the process stream of a fish processing plant were originating from the organisms being processed (Ernst *et al.* 1982). Interestingly, sample from Plant E which also processed snow crabs had PCB concentrations lower than the detection limit of the laboratory. Another clear distinction between the effluents from plants E and F (both processing snow crab) is that plant F had a significantly higher concentration of oil and grease (1117mg/L). Since PCBs are lipophilic, the concentration of PCBs found in the effluent from Plant F may be related to the concentration of oil and grease. However, oil and grease is not the only predictor of PCB since another effluent sample which had a high concentration of oil and grease (Plant G = 296mg/L) had no detectable concentrations of PCBs.

Organochlorines (pesticides) were also detected in only one plant (Plant F). No other published studies were found in which organochlorine concentrations had been measured in effluent from fish processing plants. Dieldrin, DDE and alpha-benzenehexachloride were detected in the sample from Plant F. All three chemicals bind to soil and accumulate in fatty tissue of organisms. DDE concentrations from <1 to 2 ng/L have been measured previously in Atlantic Canada surface water (CCME 1987). No Canadian guidelines for any of the organochlorines have been published to date. The USEPA has published a toxic pollutant effluent standard for DDE which is 0.001 µg/L while the concentration in the effluent from Plant F was equal to 0.139 µg/L. The dieldrin concentration in the effluent from Plant F was 0.017 µg/L which is below the water quality criteria for dieldrin in saltwater which is 0.71 µg/L. Dieldrin concentrations in Atlantic Canada surface water range from <1 to 5 ng/L (CCME 1987). No water quality criteria for alpha-benzenehexachloride have been published at the time of publication of this report.

Again, these chemicals are lipophylic and the concentration measured at Plant F may be related to the high concentrations of oil and grease in the effluent. It is recommended that another sampling event be scheduled for plant F to corroborate these results, obtain information on origin of product transformed, and obtain samples for tissue analysis for PCBs and organochlorine pesticides. Sediment sampling at the outfall is also recommended.

### 4.1.4 PBDEs

As a class, brominated flame retardants are water soluble, persistent and have a low volatility (Hale *et al.* 2001). Polybrominated diphenyl ethers (PBDEs) have been used extensively worldwide as flame retardants. In the last few years, some jurisdictions have called for the control of the emission of PBDEs. Brominated diphenyl ethers have congeners which range from bi to deca-brominated BDEs (2- to 10-BDEs). Although deca-BDE has been found in higher concentrations in the environment, a special emphasis has been placed looking at the tri to hexa-BDEs since these congeners are bioaccumulative and not easily eliminated from organisms (Environment Canada 2006).

PBDEs have been measured in a variety of environmental media such as air, soil, water (marine and freshwater), fish, mammals, birds, eggs, invertebrates, human blood, human breast milk and sewage sludge (Sellstrom *et al.* 1993, Hale *et al.* 2001, Luckey *et al.* 2002; Booji 2002). The concentrations are often closely associated with lipid content since these chemicals are hydrophobic. However no studies of PBDE concentration in effluent from fish processing have been published to date. It was hypothesized that PBDEs would be present in effluents since they are known to contain high concentrations of lipids/organics (Wells and Schneider 1975, Novatec 1993) and PBDES have been found previously in a variety of fish and invertebrates (Gama *et al.* 2006, DeBoer *et al.* 2003, Isosaari *et al.* 2005).

The comparison of the sums of PBDEs in effluent to that of previously measured in surface water (Table 4.5) demonstrates that the effluent concentrations range from one to three orders of magnitude higher than the concentrations measured in surface water. The overall sums of PBDEs in the effluent samples are higher than previously measured concentrations in fresh water (Lake Michigan (31-158 pg/L) and Lake Ontario (6 pg/L) (Stapleton and Baker 2001 and Luckey *et al.* 2002). However, PBDEs have a high affinity for organic substrates and are therefore more likely to be detected at a higher concentration in effluent than in surface water.

Table 4. 5 PBDEs concentrations in surface water and effluent

| Source | Sum of PBDEs (pg/L) | Reference |
|---|---|---|
| Lake Ontario | 6 | Luckey *et al.* 2002 |
| Lake Michigan | 31-158 | Stapleton and Baker 2001 |
| Netherlands | 6 | Booji *et al.* 2002 |
| Fish processing effluent | 82.17 - 35055 | Our study |

Regression analysis between PBDE versus ten different physical and chemical parameters measured in the water samples yielded two statistically significant relationships. A simple regression between BOD and PBDEs was statistically significant ($R^2$= 0.599, p=0.041). A multiple regression of PBDEs as a function of log transformed BOD and log transformed phosphorus show a statistically significant relationship (p=0.015, $R^2$=87.7% n=7). The small n warrants a careful interpretation of the regression results. These relationships show the affinity of PBDEs for organic substrates.

The other potential source for PBDEs (especially Hepta-, Octa-, and Deca- BDEs) in the effluent samples from fish processing plants could be from polymer mouldings, panels, synthetic rubbers and moulded plastics within the plant. There is a lot of potential of the fish products to come into contact with plastics during the transport, warehousing and processing aspects of this industry.

### 4.1.5 Mercury

In the characterization of effluent from fish processors in British Columbia (Novatec 1994), it was determined that metal concentrations were not of concern at any of the plants monitored. In the Novatec study (1994) only copper and zinc were detected in fish processing effluent. However it was determined that the source for both copper and zinc was from the tap water. A search of literature published on the characterization of effluent from fish processing plants did not locate any other data on metal concentration. Therefore, this study did not include measurements of metals in the effluent from fish processing plants except for mercury since mercury is often found in high concentrations in marine predatory pelagic species. The highest concentrations were measured in effluents from a plant processing lobster (0.57µg/L), snow crab (0.15µg/L) and shrimp (0.14µg/L). However the two other plants processing lobster had levels at or just above the detection limit of the laboratory. Since fish tissue was not analysed for mercury, it cannot be determined whether the mercury source is from the plant's equipment or from the organisms processed. In comparison, a study conducted by Health Canada (2007) revealed that on average, lobster tissue had a total mercury concentration equal to 90 µg/L, shrimp tissue had an average concentration of 50µg/L and snow crab had an average tissue concentration equal to 90µg/L. The comparison between the total mercury concentration measured in our study and fish tissue concentrations measured by Health Canada (2007) show that the effluent of the processing plants had mercury concentration which were two orders of magnitude lower.

## 4.2 Effluent Toxicity

Toxicity testing of fish processing effluent has not been conducted often. Only three studies on the toxicity of fish processing effluent were found (Wells and Schneider 1975, Novatec 1994, Wasave and Kulakarni 2004). The Wells and Schneider and Novatec studies were conducted in Canada. Wells and Schneider 1975 conducted 4-day toxicity bioassay with fingerling rainbow trout and mummichogs. Acute toxicities were expressed as $LT_{50}$'s (median lethal times for undiluted effluent). Because of limited partial mortalities, $LT_{50}$'s in hours are presented as ranges of time within which mortality occurred (Wells and Schneider 1975). Most effluents, from three processing plants, were non-lethal to test organisms (rainbow trout and mummichogs). However, samples from a fish unloading facility and from a fish meal plant showed toxicity to the rainbow trout with $LT_{50}$ (100% effluent concentration) ranging from 1-72 hours. Details on the type of sample obtained (grab, composite) were not presented.

Results from the toxicity testing of fish processing effluent which were performed in 1975 and in this study (2003-2007), as well as testing conduced in British Columbia in 1994 (Novatec 1994) are presented in Table 4.6.

Table 4.6 Toxicity Test Results

| Toxicity Test (%)* | Median (standard deviation) Our study | Range (Novatec 1994*) | Range (Wells and Schneider 1975) |
|---|---|---|---|
| Sea urchin fertilization $IC_{25}$ | 35.95 (41.37) | | |
| Sea urchin fertilization $IC_{50}$ | 67.85 (39.68) | | |
| Microtox™ $IC_{50}$ | 38.2 (38.6) | 0.67-100 | |
| Microtox™ (mortality-full strength) | 17.4 (16.7) | | |
| Stickleback $LC_{50}$ | 53.6 (35.29) | | |
| Stickleback (mortality-full strength) | 100 (49.9) | | |
| Rainbow Trout $LC_{50}$ | 35.4 (19.9) | 42 - 100 | |
| Rainbow Trout (mortality-full strength) | 100 (44.09) | | |
| Inland Silverside $IC_{25}$ | 41.1 (39.1) | | |
| Inland Silverside $LC_{50}$ | 41.2 (38.9) | | |
| Rainbow trout $LT_{50}$** (hours) | | | 1-> 96 |
| Mummichogs $LT_{50}$ (hours) | | | > 96 |
| * %; dilution of effluent from fish processing plants<br>** ; all test were 100% effluent, results are in hours | | | |

Table 4.6 reveals similar results (EC 2005) for rainbow trout and Microtox™ (*Vibrio fischeri*) toxicity testing as to those recorded in British Columbia in 1994 (Novatec 1994). Toxicity testing performed in 2003-2007 showed that effluents from fish processing plants have a wide range of toxicity. Some of the effluent collected in 2003-2007 showed no toxicity at all (lethal concentration were higher than full strength effluent – 100%) while others showed high toxicity. Effluents were most frequently toxic using the Microtox™ test. Five of the effluent samples showed were not toxic at all while fourteen effluent samples had two or more positive toxicity tests.

In the effluent samples collected by Environment Canada (2003-2007), 9 out of 11 toxicity tests had 100% mortality of rainbow trout at 100% effluent concentration (high toxicity) while the two other toxicity tests had 0% mortality at full strength effluent (100% effluent concentration). $LC_{50}$ were calculated on only four effluent samples and it ranged from < 25 to 70.7% dilutions. In comparison in the study of Novatec (1994), 3 out of 9 effluent samples had no detectable toxicity to rainbow trout, $LC_{50}$ and $LC_{25}$ > 100.

Wasave and Kulakarni (2004) exposed tilapia (*Oreochromis mossambicus*) fingerlings to a range of dilution of processing effluent (surimi processing). Unfortunately, the authors did not calculate a $LC_{50}$ for their results. In acute response experiments, the effects to tilapia ranged from 100% mortality after 11 hours at full strength effluent to 44 hours for total mortality at 20% dilution. Chronic effects were varied with 50% of the fish dying in the first 15 days of being exposed to 10% dilution of the surimi effluent while no mortality was recorded after 45 days to fingerlings exposed to 5% dilution of the processing effluent. Toxicity test results from this study were compared to the results from Novatec (1994) (Table 4.6). Both studies used rainbow trout and Microtox™. The range of values for the Microtox™ testing $IC_{50}$ was similar for both studies. Our study had a range of toxicity which was greater than that found in the Novatec study. Wells and Schneider (1975) found that some effluent from fish processing was acutely toxic to rainbow trout while other effluent were generally non-lethal to rainbow trout and mummichogs.

Sandhu (1979) created a classification scheme for acute lethal toxicity (Table 4.7). Using some of the toxicity test (LC50 and IC50) results from this study and the classification by Sandhu (1979), 18% of the effluent can be described as having a high toxicity, 34% have a moderate toxicity, 23% have a low toxicity while 25% have no detectable toxicity.

**Table 4. 7 Toxicity Classification (Sandhu 1979)**

| | Range of $LC_{50}$ (%) defining this toxicity |
|---|---|
| High toxicity | < 10 |
| Moderate toxicity | 10 – 50 |
| Low toxicity | 50 - 100 |
| Non-detectable toxicity | > 100 |

It is generally accepted that several species of organisms and a variety of endpoints ($LC_{50}$, $IC_{25}$) should be tested to estimate toxicity within an ecosystem (NovaTec 1994). NovaTec (1994) recommended against the use of the algal bioassay *Selenastrum* test for fish processing effluent testing since nutrients contained in the effluent stimulated algal growth, interfering with the test endpoint. Therefore no toxicity test using algae were conducted during this study. Overall, the lack of correlations between toxicity tests used in our study also supports the use of a battery of tests in evaluating overall toxicity of the effluent rather than an individual toxicity test using a single organism (Section 3.6.2).

Munkittrick *et al.* (1991) stated that Microtox™ provides a more sensitive assessment of toxicity than rainbow trout, Daphnia or the fathead minnow when testing complex effluent mixtures. This was the case for the majority of our study.

### 4.2.1 Relationships between effluent characteristics and toxicity

Generally BOD concentrations in effluent are due to dissolved and suspended organic waste materials. The dissolved fraction includes blood which has a very high BOD (up to 277,000 mg/L) (Novatec 1993). Most of the BOD and TSS and up to 60% of the oil and grease originates from the butchering process (Novatec 1993). Generally, lower BOD concentration can be expected from shellfish processing (Novatec 1994). The high nitrogen content is due to high blood and slime content in the effluent streams (Novatec 1994). Generally, lower ammonia concentration can be expected from shellfish processing (Novatec 1994). BOD concentrations in fish processing effluent have historically ranged from 1.54 to 277000mg/L. In the Wells and Schneider (1975) report on toxicity testing of fish processing effluent, it is estimated that the acute toxicity of one of the effluents was attributed to the high BOD level (636 and 830 mg/L). Four samples of fish processing effluent collected in 2003-2005 by Environment Canada had BOD concentrations higher than the concentrations recorded in the Wells and Schneider (1975) report. However, toxicity was reported in samples with BOD as low as 24 mg/L.

Waldon (1991) reported that the untreated effluent from a fish processing plant caused low dissolved oxygen concentrations in a Bayou in Louisiana which violated the dissolved oxygen criterion in use in the state of Louisiana. Since the toxicity testing of our samples employed aeration, we cannot assess the effect of oxygen depletion on our tests.

In general, all toxicity tests results in our study were statistically influenced by one or more physical and chemical parameters. Statistically significant negative relationships between toxicity test results and oil and grease or BOD were detected for most toxicity tests.

Statistically significant positive relationships were detected between toxicity tests results and calcium or sulphate (simple regressions) and major ions (principal component analysis). However all of the statistically significant relationships did not account for all of the variability in the dataset ($R^2$ varied from 20 to 63%) which led us to hypothesize that although these parameters were predicting part of the response of the organisms to the toxicity testing there were other unknown factors which influence the toxicity values. The toxicity tests which had the highest $R^2$ (most of the variability of the data explained) were inland silverside $IC_{25}$, $LC_{50}$ and stickleback $LC_{50}$ for both simple regressions and principal component analysis while the toxicity test results for Microtox™ had the lowest $R^2$ of all statistically significant relationship with 20 to 30% of the variability explained by sulphate, calcium or major ions (principal component analysis). It is interesting to note that the parameters linked to nutrients (oil and grease, BOD) explained a higher proportion of the variability of the dataset.

## 4.3 Comparison by processing categories

The comparison by processing categories according to Beaudin (2001) showed that a tertiary processing resulted in an effluent with higher levels of nutrients (BOD, TN, TP, $NH_3$ etc) (Section 3.3). This is a reflection of the additional processes that occur in tertiary processing that result in fish being handled (prepared) more extensively and therefore more likely to break down into smaller particles which are not caught by the screens in place at the effluent outfalls of the fish plants.

Another result in Section 3.3 was presented in Figure 3.12 which showed that in general primary processing effluent registered the least toxicity to various organisms while tertiary processing showed the highest toxicity. These relationships are a reflection of the characteristics of the effluent since effluent from tertiary processing contains the highest concentrations of nutrients and high nutrient levels are significantly correlated to toxicity (see section 3.2.9).

## 4.4 Effect of Effluent Treatment

Effluent treatment options for fish processing plants have been described in previous literature with numerous systems such as dissolved air flotation (DAF), precipitation, membrane filtration, biological treatment (aerobic and anaerobic) having their unique characteristics and advantage/disadvantages (Novatec 1994).

One of the plants sampled had a dissolved air flotation (DAF) unit installed to reduce its organic loading to the environment. DAF units are known to significantly reduce organic loads such as BOD, TSS, oil and grease when used in conjunction with flocculants or coagulants (Sano 1988, Novatec 1994, Usydus and Bykowski 1999). Effluent from this plant was collected at the outfall from the DAF unit. The effluent before the DAF unit was pink in color while it had no noticeable colour after leaving the DAF unit. Concentrations of parameters such as BOD, TSS and oil and grease were within the range of values detected in all other plants sampled in this project, even after passing through the DAF unit. These parameters were not reduced to the lowest values we recorded in other plants but this was the only plant which processed shrimp and therefore we were not able to compare to another processing shrimp. Sampling of another facility processing shrimp and which does not possess a DAF unit is recommended. Of particular interest were the toxicity values for this plant which were also within the range of values previously detected at other processing plants for the following toxicity tests; urchin $IC_{25}$ and

$IC_{50}$ and Microtox™ $IC_{50}$. The effluent from this plant was most toxic of all effluents tested for Stickleback $LC_{50}$ and Inland silverside $IC_{25}$ and $LC_{50}$.

Bench scale studies performed by Jamieson *et al.* 2006 showed that DAF systems reduce BOD, TSS and COD from fish processing effluent. Jamieson *et al.* 2006 also show that alum coagulation improved overall treatment efficiency in DAF systems. However both raw and DAF treated effluent from salmon and groundfish processing were toxic to *Vibrio fischeri* (Microtox™). The $EC_{50}$ value for raw effluent was lower by 20-26% than the value for the DAF treated effluent (Jamieson *et al.* 2006).

It is also important to note that the differences in effluent characteristics and toxicity level of effluent could be a reflection of processing category (Section 3.3 and 4.3) and efficiency of screening of the effluent depending on the category of processing which should be further studied.

## 5.0 RECOMMENDATIONS

- Sampling of the wastewater at plants processing species which we haven't sampled yet; for example; Atlantic salmon, oysters, mackerel, haddock, etc (Section 4.2).
- Replicate sampling at a plant conducting the same processing activities or fish species would show the inherent variability in physical and chemical parameters and toxicity testing of fish processing effluent (Section 4.2).
- It is recommended that we investigate further the usage and potential toxicity of chemicals (sanitizers, cleaners, disinfectants etc) discharged in effluent from fish processing washdown. This is an area where changes in chemicals to less toxic equivalents might yield rapid and significant results (Section 4.8).
- Collecting information on chemical usage pattern of all fish processing plants in Canada is recommended since these data are not collected by any provincial or federal agencies (Section 4.8).
- It is recommended that chlorine concentration at fish processing plants be measured more precisely (Section 4.9.1).
- Based on the results of this study, environmental monitoring of receiving environment is required to further increase our knowledge of the environmental effects of this effluent.

## 6.0 REFERENCES

AMEC. 2003. Management of wastes from fish processing operations. Report submitted to National Programme of Action Atlantic Regional Team. Environment Canada – Atlantic Region.

Anguiar A.L.C and G.L. Sant'Anna. 1988. Liquid effluent of the fish canning industries of Rio de Janeiro state – treatment alternatives. Env. Tech. Letters. Vol 9. 421-428.

Beaudin, M., 2001 - Towards Greater Value: Enhancing Eastern Canada's Seafood Industry. The Canadian Institute for Research on Regional Development, Maritimes Collection, Monographs, 301 pp.

Booji K., Zegers B.N. Boon J.P. 2002. Levels of some polybrominated diphenyl ether (PBDE) flame retardants along the Dutch coast as derived from their accumulation in SPMDs and blue mussels (*Mytilus edulis*). Chemosphere. 46: 683-688.

Canadian Food Inspection Agency. 2003. Reference Listing of Accepted Construction Materials, Packaging Materials and Non-Food Chemical Products. http://www.inspection.gc.ca/english/ppc/reference/introe.shtml

Carawan R.E. 1991. Processing Plant Waste Management guidelines. Fish and the environment – 1991. Pollution Prevention Short Course. North Carolina state University.

Carawan R.E., Chamber J.V., Zall R.R. and R. Wilkowske. 1979. Spinoff on fish water and wastewater management. Extension Special Report No. AM-18F. north Carolina state University, Cornell University and Perdue University and Science and Education administration-Extension USDA Washington D.C.

CCME (Canadian Council of Ministers of the Environment). 1987 (plus updates to 1994). Canadian Water Quality Guidelines. Environment Canada. Ottawa, ON.

CCME (Canadian Council of Ministers of the Environment). 1999. Canadian Water Quality Guidelines for the Protection of Aquatic Life.
DeBoer J., Wester P.G., van der Horst and P.E.G. Leonards. 2003. Polybrominated diphenyl ethers in influents, suspended particulate matter, sediments, sewage treatment plant and effluents and biota from the Netherlands. Environmental Pollution. 122(1): 63-74.

Eisler R. 1986. PCB hazard to fish, wildlife and invertebrates; a synoptic review. US Fish and Wildlife Service. Contaminant Hazard Reviews. Report No.7.

Environment Canada. 1975. Fish Processing Operations Liquid Effluent Guidelines. Regulations, Codes and protocols Report EPS 1-WP-75-1

Environment Canada. 1990. "Biological Test Method: Acute Lethality Test Using Threespine Stickleback (*Gasterosteus aculeatus*) EPS 1/RM/10"

Environment Canada.1992a. "Biological Test Method: Toxicity Test Using Luminescent Bacteria, *Photobacterium phosphoreum*"

Environment Canada. 1992b. Biological Test Method: Fertilization Assay Using Echinoids (Sea Urchins and Sand Dollars. EPS 1/RM/27.

Environment Canada. 1993. Guidance Manual for the Categorization of Organic and Inorganic Substances on Canada's Domestic Substances List. Existing Substances Branch

Environment Canada. 1999. Fact sheet; the future of the former Irving Whale site. http://www.ns.ec.gc.ca/whale2/99-03-11_back.html

Environment Canada. 2000. "Biological Test Method: Reference Method for Determining Acute Lethality of Effluents Rainbow Trout EPS 1/RM/13 2nd Edition"

Environment Canada. 2001. Priority substance list assessment report. Ammonia in the aquatic environment.

Environment Canada. 2005. Industry profile and review of pollution prevention and effluent treatment. Options for BC fish processing operations. January 2005.

*EPA. 1974.* TITLE 40--Protection of Environment. Chapter 1 – Subchapter N – Effluent guidelines and standards. 39 FR 4532, Feb. 1, 1974.

Ernst B., Hawkins V. and K.L. Tay. 1982. Investigation of the cause and extent of PCB contamination of Petit-de-Grat Harbour Nova Scotia. Environment Canada. EPS-5-AR-82-2

Fahim F.A., Fleita D.H., Ibrahim A.M. and F.M.S. El-Dars. 2001. Evaluation of some methods for fish canning wastewater treatment. Water, air and soil Pollution. 127: 205-226.

Gama A.C., Sanatcumar P., Viana P., Barcelo D. and J.C. Bordado. 2006. The occurrence of polybrominated diphenyl ethers in river and coastal biota from Portugal. Chemosphere 64: 306-310.

Gonzalez J.F., Civit E.M and H.M. Lupin. 1983. Composition of fish filleting wastewater. Water South Africa; 9:49-56

Hale. R.C. M.J. La Guardia M.J., Harvey E.P. Mainor T.M. Duff W.H. and M.O. Gaylor. 2001. Polybrominated diphenyl ether flame retardants in Virginia freshwater fishes (USA). Environ. Sci. Tech. 35(23): 4585-4591.

Halstead, BW. 1988. Poisonous and Venemous Marine Animals of the World, 2nd Ed. The Darwin Press, Inc. Princeton, NJ.

Health Canada. March 2007. Human Health Risk Assessment of Mercury in Fish and Health Benefits of Fish Consumption. Bureau of Chemical Safety; Food Directorate; Health Products and Food Branch

Isosaari P., Hallikainene A., Kiviranta H., Vuorinen P.J. Parmanne R., Koistinen J and T. Vartiainen. 2005. Polychlorinated dibenzo-p-dioxins, dibenzofurans, biphenyls, naphthalenes and polybrominated diphenyl ethers in the edible fish caught from the Baltic Sea and lakes in Finland. Environmental Pollution. In Press. 1-13.

Jamieson L. 2006. A preliminary assessment of the potential; impact of fish processing effluent on the aquatic environment. Submitted in partial fulfillment of the requirements for the degree of Master of Applied Science. Dalhousie University.

Kumbhare A.R. 1975. Characteristics of fish plant wastes in Nova Scotia and their effects on coastal bays II : Waste water characterisation. EPS-8-AR-75-3.

Luckey F.J., Fowler B. and S. Litten. 2002. Establishing baseline levels of polybrominated diphenyl ethers in Lake Ontario surface waters. Unpublished manuscript 2002/03/01. New York state Department of Environmental conservation, Division of water, Albany, NY.

Ministère de l'environnement et de la faune du Québec. 1995. Guide technique sectoriel. Usines de transformation de produits marins. 40pp.

Munkittrick K.R., Power E.A. and G.A. Sergy. 1991. The relative sensitivity of Microtox™, dapnid, rainbow trout, and fathead minnow acute lethality tests. Environ. Toxicol. Water Quality 6: 35-62.

NovaTec Consultants Inc. 1993. Wastewater handling in selected fish processing plants in Northern Europe – a report to the Fisheries Council of British Columbia.

NovaTec Consultants Inc. 1994. Guide for best management practices for process wastewater management at fish processing plants in British Columbia. Fraser River Action Plan.

NovaTec Consultants Inc. 1995. Technical guide for the development of pollution prevention plants for fish processing operations in the Lower Fraser Basin. Fraser River Action Plan.

NovaTec consultants Inc. and EVS Environment Consultants. 1994. Wastewater characterisation of fish processing plant effluents – A report to water quality/ waste management committee, Fraser River Management committee

Park E., Enander R., Barnett M.S., and C. Lee. 2001. Pollution prevention and biological oxygen demand reduction in a squid processing facility. J. Cleaner Prod. 9: 341-349.

Payne, J. F.., I. Martins, D. Fagan and A. Rahimtula. 1980. Mutagens in the Aquatic Environments: Water Chlorination and Petroleum Sources of Polycyclic Aromatics as Major Contributors. In: Water Chlorination Environmental Impact and Health Effects, Volume 3. Ann Arbor Science, Ann Arbor Michigan, 850 p. Edited by Jolley, R.L., W.A. Brungs, and R.B. Cummings.Simpson, B.K., Gagne, N., and Simpson, M.V. 1994Bioprocessing of chitin and chitosan. In Martin, A.M. (ed.) Fisheries Processing: Biotechnological applications. Chapman & Hall, London.

Sandhu S.S. 1979. Short term biotesting of environmental effluents. P. 225-230. In: Ayers F.A. Symposium proceedings: Textile Industry Technology (December 1978, Williamsburg, VA). US EPA, EPA0600/2-79-104. 376p.

Sano K. 1988. Treatment of wastewater from marine products processing plants. Mar. Behav. Physiol. 14: 41-63.

Sellstrom U. Jansson B., Kierkegaard A., deWilt C., Odsjo T. and M. Olsson. 1993.

Polybrominated diphenyl ethers (PBDE) in biological samples from the Swedish environment. Chemosphere. 26:1703-1718.

Usydus Z. and P.J. Bykowski. 1999. Treatment of wastewater from fish processing factories. Bull. Sea Fisheries Institute. 1(146):71-84.

Usydus Z. and P.J. Bykowski. 1998. Chemical characteristics of wastewater in the fish processing industry. Bull. Of the sea fisheries institute. 1(143): 63-73.

Waldon M. 1991. Bayou Grand Caillou water quality study: shrimp processor discharge impact assessment. Office of water resources. Louisiana department of environmental quality.

Walsh M.E., Chaulk M. and G.A. Gagnon. 2004. Preliminary assessment of effluents generated by seafood processors in the Atlantic Region. Centre for Resource Studies. Dalhousie University.

Wasave S.M. and G.N. Kulakarni. 2004. Surimi wastewater characteristics and its toxicity to the fingerlings of Tilapia, *Oreochromis mossambicus*. Poll. Res. 22(2): 125-130.

Wells P.G. and J.R. Schneider. 1975. Characteristics of fish plant wastes in Nova Scotia and their effects on coastal bays III : Toxicity Studies. EPS-8-AR-75-4.

Personal Communications

Doe, Ken. Environment Canada. Head Toxicology Laboratory, Environmental quality Laboratory, Moncton, NB. January 2007.

Donald, Jack. Canadian Food Inspection Agency. Technical Program Officer. Ottawa, ON. May 2005.

Li, Anita. Environment Canada. Project Engineer, Downsview ON. January 2006

Robichaud, Robert. Environment Canada. Enforcement Branch. Fredericton, NB. July 2006.

# APPENDIX A

## QUESTIONNAIRE FOR FISH PROCESSING PLANTS

| GENERAL INFORMATION | |
|---|---|
| Company Name | |
| Name of Plant | |
| Location (address/ lat/long) | |
| Contact | |
| Phone/Fax/e-mail | |
| **Process Details** | |
| Process Type | |
| Product Type | |
| Volume of species processed/ day/ month/yr | |
| Season of operation (if any) | |
| Sequence (order of licensed species) | |
| Raw Product Source | |
| Plant Capacity | |
| Offload Vessel Method | |
| Process Chemicals (name, location, timing and amounts used) | |
| Cleaning Chemicals (name, location, timing and amounts used) | |
| Disinfectant Chemicals (name, location, timing and amounts used) | |
| Pesticide Usage (name, location, timing and amounts used) | |
| Water consumption / day (treated) | |
| Water Source | |
| **Waste Treatment** | |
| Type of effluent treatment | |
| Sewage Treatment method | |
| Offal Transport Method (wet or dry) | |
| Offal fate | |

| | |
|---|---|
| Effluent Screening Type | |
| Chemicals used in effluent treatment | |
| Solid wastes (volume or weight) (is it based on volume/weight of fish processed) | |
| **Effluent Data** | |
| Discharge Flow (m/s) | |
| Discharge Volume ($m^3$/day) | |
| Discharge Chemistry (pH, TSS, DO etc) | |
| **Outfall Data** | |
| Outfall Design (temporary/ permanent) | |
| Lat/Longitude | |
| Discharge to marine/ freshwater | |
| Name of receiving waterbody | |
| Habitat of receiving waterbody | |
| Depth of outfall at low tide | |
| Distance to outfall from shore at low tide | |
| Pipe diameter | |
| Pipe material | |
| Diffuser configuration | |
| Age of outfall | |
| Chemistry at outfall (ex; DO) | |

# APPENDIX B
# PHYSICAL AND CHEMICAL AND TOXICITY TESTING RESULTS

| Parameter/Processing Plant | Units | Plant A | Plant B | Plant C | Plant D | Plant E | Plant F | Plant G | Plant H | Plant I-a | Plant I-b | Plant I-c | Plant I-d | Plant J | Plant K | Plant L | Plant M | Plant N | Plant O |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | F-pollock | Clam | Mussel | Lobster | S crab | S crab | Herring | Salmon | J. crab | Scallop | Lobster-pm | Lobster-am | Algae | Herring | redfish | cod | fish meal | y flounder |
| Date of Sample collection | | 15-Apr-03 | 29-Apr-03 | 13-May-03 | 27-May-03 | 31-Jul-03 | 10-Sep-03 | 20-Oct-04 | 19-Nov-04 | 8-Dec-04 | 8-Dec-04 | 8-Dec-04 | 8-Dec-04 | 14-Dec-05 | 4-Jan-05 | 1-Jun-05 | 7-Jun-05 | 3-Aug-05 | 12-Sep-05 |
| *Analytical Results* | | | | | | | | | | | | | | | | | | | |
| Total Hardness | mg/L | 3708 | 5585 | 4443 | 247.4 | 290.1 | 55.03 | 5225 | 5.19 | 4725 | 4953 | 3283 | 2985 | 115 | 42.4 | 4096 | 2042 | 5724 | 5078 |
| Chloride | mg/L | 13335 | 18558 | 13451 | 380.4 | 106 | 175.4 | 15766 | 32.4 | 15514 | 15672 | 10241 | 9557 | 90.3 | 151.8 | 12408 | 6231 | 16942 | 15250 |
| Sulphate | mg/L | 1731 | 2444 | 1888 | 29.92 | 372.3 | 25.47 | 2258 | 4.7 | 2199 | 2223 | 1450 | 1343 | 107.8 | 22.9 | 1924 | 204.6 | 2306 | 1981 |
| Nitrate | mg/L | <0.20 | 3.47 | 5.84 | 0.06 | <0.02 | <0.02 | <0.20 | <0.10 | <2.00 | <2.00 | <2.00 | <2.00 | <0.20 | <0.20 | <0.1 | <0.1 | <0.5 | <0.1 |
| Magnesium dissolved | mg/L | 713.1 | 1127 | 867.7 | 23.38 | 14.42 | 9.55 | 1068 | 0.46 | 968 | 1013 | 673 | 616.3 | 16.53 | 2.6 | 826 | 397.1 | 1162 | 1014 |
| Potassium dissolved | mg/L | 278 | 357.5 | 261.4 | 7.73 | 6.22 | 27.2 | 379 | 3.02 | 318 | 303 | 225 | 230.6 | 544 | 23.3 | 239.3 | 162.7 | 345.2 | 373.7 |
| Sodium dissolved | mg/L | 6975 | 9915 | 7606 | 174.8 | 138.9 | 93.5 | 9346 | 154.8 | 8264 | 8579 | 5631 | 5219 | 142 | 123 | 6990 | 3527 | 9235 | 8565 |
| Calcium dissolved | mg/L | 309 | 377.6 | 348.4 | 60.53 | 92.39 | 6.29 | 331 | 1.32 | 296 | 313 | 205 | 179 | 18.6 | 12.7 | 278.3 | 162.9 | 375.8 | 361.1 |
| Nitrogen, Ammonia | mg/L | 12.3 | 0.06 | 2.01 | 0.34 | 1.22 | 3.43 | 2.37 | 0.26 | 0.92 | 0.43 | 0.32 | 0.61 | 3.41 | 0.91 | 1.53 | 6.11 | 12.83 | 0.68 |
| Total Nitrogen | mg/L | 33.24 | <0.01 | 7.47 | 2.9 | 7.35 | 131.3 | 19.32 | 2.72 | 24.4 | 17.98 | 4.38 | 19.71 | 35.14 | 19.91 | 12.75 | 75.26 | 67.78 | 17.85 |
| Total Organic Carbon | mg/L | 101.1 | 52.3 | 212.9 | 94.9 | 7.4 | 1134 | 103.6 | 72.8 | 71 | 105.4 | 100.2 | 82.5 | 909.2 | 3 | 6.3 | 113.1 | 279.3 | 149.1 |
| Phosphorous | mg/L | 7.546 | 0.162 | 1.885 | 0.574 | 1.468 | 9.616 | 6.082 | 1.723 | 4.899 | 4.714 | 0.729 | 1.876 | 23.13 | 9.986 | 4.12 | 81.98 | 15.38 | 14.97 |
| Aldrin | mg/L | <0.5 | <0.5 | <0.5 | <0.5 | <9 | <11 | <2 | <2 | <2 | <2 | <2 | <2 | <2 | <2 | n/a | n/a | n/a | n/a |
| Alpha-benzenehexachloride | ng/L | <0.5 | <0.5 | <0.5 | <0.5 | <14 | 36 | <9 | <9 | <9 | <9 | <9 | <9 | <9 | <9 | n/a | n/a | n/a | n/a |
| Alpha-chlordane | ng/L | <0.5 | <0.5 | <0.5 | <0.5 | <8 | <11 | <8 | <8 | <8 | <8 | <8 | <8 | <8 | <8 | n/a | n/a | n/a | n/a |
| Gamma-chlordane | ng/L | <0.5 | <0.5 | <0.5 | <0.5 | <11 | <14 | <11 | <11 | <11 | <11 | <11 | <11 | <11 | <11 | n/a | n/a | n/a | n/a |
| O,P'-DDD | ng/L | <0.5 | <0.5 | <0.5 | <0.5 | <11 | <13 | <11 | <11 | <11 | <11 | <11 | <11 | <11 | <11 | n/a | n/a | n/a | n/a |
| P,P'-DDD | ng/L | <0.5 | <0.5 | <0.5 | <0.5 | <9 | <11 | <9 | <9 | <9 | <9 | <9 | <9 | <9 | <9 | n/a | n/a | n/a | n/a |
| O,P'-DDE | ng/L | <0.5 | <0.5 | <0.5 | <0.5 | <6 | <11 | <6 | <6 | <6 | <6 | <6 | <6 | <6 | <6 | n/a | n/a | n/a | n/a |
| P,P'-DDE | ng/L | <0.5 | <0.5 | <0.5 | <0.5 | <10 | 139 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | n/a | n/a | n/a | n/a |
| O,P'-DDT | ng/L | <0.5 | <0.5 | <0.5 | <0.5 | <7 | <11 | <7 | <7 | <7 | <7 | <7 | <7 | <7 | <7 | n/a | n/a | n/a | n/a |
| P,P'-DDT | ng/L | <0.5 | <0.5 | <0.5 | <0.5 | <9 | <11 | <9 | <9 | <9 | <9 | <9 | <9 | <9 | <9 | n/a | n/a | n/a | n/a |
| Dieldrin | ng/L | <0.5 | <0.5 | <0.5 | <0.5 | <7 | 17 | <7 | <7 | <7 | <7 | <7 | <7 | <7 | <7 | n/a | n/a | n/a | n/a |
| Alpha-endosulfan | ng/L | <0.5 | <0.5 | <0.5 | <0.5 | <42 | <51 | <42 | <42 | <42 | <42 | <42 | <42 | <42 | <42 | n/a | n/a | n/a | n/a |
| Beta-endosulfan | ng/L | <0.5 | <0.5 | <0.5 | <0.5 | <6 | <14 | <6 | <6 | <6 | <6 | <6 | <6 | <6 | <6 | n/a | n/a | n/a | n/a |
| Endrin | ng/L | <0.5 | <0.5 | <0.5 | <0.5 | <10 | <14 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | n/a | n/a | n/a | n/a |
| Heptachlor epoxide | ng/L | <0.5 | <0.5 | <0.5 | <0.5 | <9 | <11 | <9 | <9 | <9 | <9 | <9 | <9 | <9 | <9 | n/a | n/a | n/a | n/a |
| Gamma-benzenehexachloride | ng/L | <0.5 | <0.5 | <0.5 | <0.5 | <4 | <11 | <4 | <4 | <4 | <4 | <4 | <4 | <4 | <4 | n/a | n/a | n/a | n/a |
| P,P'-methoxychlor | ng/L | <0.5 | <0.5 | <0.5 | <0.5 | <13 | <15 | <13 | <13 | <13 | <13 | <13 | <13 | <13 | <13 | n/a | n/a | n/a | n/a |
| Mirex | ng/L | <0.5 | <0.5 | <0.5 | <0.5 | <12 | <15 | <12 | <12 | <12 | <12 | <12 | <12 | <12 | <12 | n/a | n/a | n/a | n/a |
| Oil and Grease | mg/L | NA | <1.0 | 4 | 11.8 | 12.1 | 1117 | 296 | 81 | 1 | <1 | 9 | 14 | 11 | 33 | 28 | 6 | 97 | 42 |
| Total PCBs | ng/L | <1.0 | <1.0 | <1.0 | <1.0 | <75 | 233 | <10.0 | <10.0 | <10.0 | <10.0 | <10.0 | <10.0 | <10.0 | <10.0 | <10.0 | <10.0 | n/a | n/a |
| Specific conductivity | us/cm | NA | 45200 | 34500 | 1399 | 1287 | not appl | NA | NA | 39400 | 38800 | 26700 | 25500 | 1787 | 771 | n/a | n/a | 43500 | 42000 |
| pH | | 6.86 | 7.71 | 7.05 | 7.1 | 6.99 | 5.97 | 5.77 | 10.63 | 6.8 | 6.51 | 6.76 | 6.56 | 7.34 | 6.96 | 6.8 | 6.7 | 6.39 | 6.33 |
| BOD dissolved | mg/L | 147 | 40 | 66 | 24 | 104 | 2230 | 342 | 115 | 162 | 82 | 54 | 204 | 493 | 145 | 97 | n/a | 654 | 2415 |
| Total dissolved solids | mg/L | 60 | 40 | 520 | 20 | TC | 119 | | | | | | | | | 33581 | 18030 | | 29170 |
| Total suspended solids | mg/L | 69.7 | 55.1 | 558.6 | 9.5 | <1 | 1192 | 347 | 85.5 | 179 | 56 | 31 | 79 | 226 | 64 | 118.6 | 77 | 697 | 549 |
| Volatile solids | mg/L | | | | | | | 302 | 825 | 105 | 36 | 23 | 63 | 76 | <20 | <20 | <20 | 515 | 363 |
| Total mercury | ug/L | 0.04 | <0.02 | 0.03 | <0.02 | 0.04 | 0.15 | 0.02 | <0.02 | 0.03 | 0.06 | 0.02 | 0.03 | <0.02 | 0.04 | 0.05 | 0.09 | 0.09 | 0.07 |
| PBDE (sum) (blank corrected) | pg/L | | | | | | | | | 4719.34 | 82.17 | | 12805.32 | | 4603.92 | 1965.64 | 35055.28 | 6445.08 | |
| *Field Measurements* | | | | | | | | | | | | | | | | | | | |
| Total chlorine | mg/L | 0.25 | 0.25 | 0.1 | 0.5 | 0.1 | 0 | *0* | *0* | *0* | *0* | *0* | *0* | *0* | *0* | *0* | *0.5* | *0* | *0* |
| Free chlorine | mg/L | 0 | 0.2 | 0 | 0 | 0 | 0 | *0* | *0* | *0.5* | *0.5* | *0.5* | *0.5* | *0.5* | *0.5* | *0* | *0.5* | *0* | *0.5* |
| Dissolved oxygen | mg/L | 11.4 | 11.19 | 5.85 | 9.46 | 8.28 | 8 | *1.4* | *12.52* | *12.92* | *10.78* | *12.1* | *10.5* | *1.3* | *13.1* | *8.95* | *10.34* | *5.69* | *10.59* |
| Temperature | C | 92.2 | 94.4 | 49.7 | 81.9 | 78.4 | 85.9 | | | | | | | | | | | | |
| pH | | 6.1 | 7 | 8 | 10 | 11 | 15 | *11* | *8.7* | *5* | *4.4* | *2.8* | *2.5* | *10.4* | *9.2* | *18.5* | *8.6* | *25.5* | *11.7* |
| Salinity | % | 7.4 | 8 | 7.4 | 8.3 | 7.9 | 7.5 | | *11.2* | *8* | *8* | *8* | *7.5* | *7.8* | *7* | *7* | *7* | *8.4* | *7* |
| | | 18 | 28 | 22 | 0 | 0 | 1 | 25 | *0* | *22* | *23* | *12* | *20* | *0* | *0* | *25* | *10* | *32* | *24* |
| *Toxicity Tests* | | | | | | | | | | | | | | | | | | | |
| Sea urchin fertilization IC25 | % | >100 | >100 | >100 | >100 | *9.2* | *17* | *21.9* | *6.02* | *> 100* | *> 100* | *23.2* | *sampler mal* | *1.93* | 56.1 | *48.7* | *>76.9* | *2.9* | *7.97* |
| Sea urchin fertilization IC50 | % | >100 | >100 | >100 | >100 | 16.5 | 29.7 | 68.7 | 9.29 | > 100 | > 100 | 37.2 | *sampler mal* | 6.11 | > 67 | >95 | >76.9 | 4.61 | *20.3* |
| Microtox IC50 | % | >100 | >100 | >100 | 38.2 | >100 | 21.5 | 37.6 | 1.43 | > 99 | > 99 | 15.2 | *sampler mal* | 0.297 | 10.2 | 63.4 | 29.8 | >99 | >100 |
| Microtox (decrease at full strength) | % | 30.9 | 1.1 | 41.1 | | 27.5 | | | | 7.3 | 3.6 | | *sampler malfunction* | | | | | | |
| Stickleback LC50 | % | >100 | >100 | >100 | not tested | not tested | not tested | 37.9 | 70.7 | not tested | not tested | not tested | *sampler mal* | 25.7 | 53.6 | not tested | not tested | 46.7 | 56.1 |
| Stickleback (Mortality at full strenght) | % | 0 | 0 | 0 | 0 | 0 | 100 | 100 | 100 | 0 | 0 | 100 | *sampler mal* | 100 | 100 | not tested | not tested | 100 | 100 |
| Rainbow Trout LC50 | % | not tested | not tested | not tested | not tested | not tested | not tested | not tested | not tested | not tested | not tested | not tested | *sampler mal* | < 25 | 35.4 | 70.7 | 35.4 | not tested | not tested |
| Rainbow Trout (Mortality at full strenght) | % | not tested | not tested | not tested | 0 | 0 | 100 | not tested | 100 | not tested | not tested | not tested | *sampler mal* | 100 | 100 | 100 | 100 | not tested | not tested |
| Inland Silversides IC25 % v/v | % | 54 | > 100 | > 100 | > 100 | > 100 | 14.5 | 52.6 | 43.9 | n/a | n/a | n/a | *sampler mal* | 14.4 | 28.9 | >100 | 41.2 | 41 | n/a |
| Inland Silversides LC50 % v/v | % | 53.6 | > 100 | > 100 | > 100 | 89.6 | < 6.25 | 50 | 32.4 | n/a | n/a | n/a | *sampler mal* | 13.6 | 28.8 | >100 | 59.5 | 53.6 | n/a |

| Plant P | Plant Q | Parameter/Processing Plant | Plant R | Plant S | Plant T | Plant U | Plant V | Plant V-a |
|---|---|---|---|---|---|---|---|---|
| s cucs | lobster | | shrimp | atl salmon | atl salmon | atl salmon | snow crab | cleaning |
| 13-Sep-05 | 27 Sep-05 | Date of Sample collection | 26-Oct-05 | 26 fev 200 | 27 fev 200 | 28 fev 200 | 12-Jun-07 | 12-Jun-07 |
| | | | | | | | | |
| | | *Analytical Results* | | | | | | |
| 5349 | 2018 | Total Hardness | 2684 | 2966 | 151 13 | 1175 | 2053 | 3625 |
| 16803 | 1821 | Chloride | 6371 | 9350 | 451 | 4180 | 8186 | 10908 |
| 1948 | 214 3 | Sulphate | 1078 | 1700 | 82 | 587 | 897 2 | 2041 |
| <0 1 | <0 1 | Nitrate | <0 1 | <0 002 | <0 002 | 0 054 | <0 1 | <0 1 |
| 1078 | 185 | Magnesium dissolved | 416 | 604 | 29 3 | 222 | 399 | 728 |
| 403 9 | 29 2 | Potassium dissolved | 156 | 199 | 21 3 | 119 | 139 | 218 |
| 9082 | 1662 | Sodium dissolved | 3294 | 4820 | 255 | 1950 | 3643 | 6098 |
| 363 9 | 503 | Calcium dissolved | 389 | 196 | 12 4 | 106 | 164 | 251 |
| 0 22 | 0 86 | Nitrogen, Ammonia | 13 31 | 3 33 | 17 8 | 8 82 | 42 67 | 10 98 |
| 13 92 | 29 65 | Total Nitrogen | 154 3 | 81 | 64 | 145 | 45 47 | 13 59 |
| 724 6 | 9 6 | Total Organic Carbon | 683 6 | 347 | 334 | 521 | 52 | 15 1 |
| 26 85 | 8 026 | Phosphorous | 23 | 5 6 | 7 2 | 21 9 | 3 83 | 1 449 |
| n/a | n/a | Aldrin | n/a | | | | | |
| n/a | n/a | Alpha-benzenehexachloride | n/a | | | | | |
| n/a | n/a | Alpha-chlordane | n/a | | | | | |
| n/a | n/a | Gamma-chlordane | n/a | | | | | |
| n/a | n/a | O,P'-DDD | n/a | | | | | |
| n/a | n/a | P,P'-DDD | n/a | | | | | |
| n/a | n/a | O,P'-DDE | n/a | | | | | |
| n/a | n/a | P,P'-DDE | n/a | | | | | |
| n/a | n/a | O,P'-DDT | n/a | | | | | |
| n/a | n/a | P,P'-DDT | n/a | | | | | |
| n/a | n/a | Dieldrin | n/a | | | | | |
| n/a | n/a | Alpha-endosulfan | n/a | | | | | |
| n/a | n/a | Beta-endosulfan | n/a | | | | | |
| n/a | n/a | Endrin | n/a | | | | | |
| n/a | n/a | Heptachlor epoxide | n/a | | | | | |
| n/a | n/a | Gamma-benzenehexachloride | n/a | | | | | |
| n/a | n/a | P,P'-methoxychlor | n/a | | | | | |
| n/a | n/a | Mirex | n/a | | | | | |
| 79 | 28 | Oil and Grease | 93 | n/a | n/a | 16 6 | 32 | 9 |
| n/a | n/a | Total PCBs | n/a | n/a | n/a | n/a | | |
| 46200 | 10960 | Specific conductivity | 19060 | 5110 | 1840 | 3210 | 18640 | 29300 |
| 5 98 | 7 6 | pH | 7 05 | 6 98 | 6 55 | 6 97 | 6 78 | 6 98 |
| 4585 | 216 | BOD dissolved | 2062 | 101 | 137 | 670 | 434 | 83 |
| 31640 | 7660 | Total dissolved solids | 13220 | 16800 | 1230 | 6740 | | |
| 693 | 215 | Total suspended solids | 479 4 | 1280 | 123 | 514 | 139 3 | 6 5 |
| 398 | 167 | Volatile solids | 334 | n/a | n/a | n/a | | |
| 0 03 | 0 57 | Total mercury | 0 14 | <0 02 | <0 02 | 0 04 | <0 02 | <0 02 |
| | | PBDE (sum) (blank corrected) | 14502 69 | | | | | |
| | | | | | | | | |
| | | | | | | | | |
| | | *Field Measurements* | | | | | | |
| *0* | *0* | Total chlorine | *0* | *0* | *0* | *0* | *0* | *0* |
| *0* | *0* | Free chlorine | *0* | *0 5* | *0 5* | *0* | *0* | *0* |
| *9 94* | *5 64* | Dissolved oxygen | *8 87* | *8 5* | *8* | *8 25* | | |
| | | Temperature | | | | | *16 1* | *11 9* |
| *11 5* | *11* | pH | *10 6* | | | | | |
| *7 8* | *6 8* | Salinity | *8 4* | *7* | *6 2* | *7 2* | *7 2* | *7 2* |
| *26* | *5* | | *10* | *19* | *0* | *0* | *6* | *9* |
| | | *Toxicity Tests* | | | | | | |
| *2 37* | *65 1* | Sea urchin fertilization IC25 | *6 19* | n/a | n/a | n/a | n/a | n/a |
| *6 33* | >72 | Sea urchin fertilization IC50 | *9 71* | n/a | n/a | n/a | n/a | n/a |
| *41 8* | 12 4 | Microtox IC50 | 20 3 | 25 5 | 33 6 | 13 7 | >99 | >45 |
| | | Microtox (decrease at full strength) | | | | | | |
| <6 3 | >100 | Stickleback LC50 | 19 5 | <6 25 | 17 7 | 28 7 | 70 7 | >100 |
| *100* | 0 | Stickleback (Mortality at full strenght) | 100 | 100 | 100 | 100 | 100 | 0 |
| not tested | not tested | Rainbow Trout LC50 | not tested | not tested | not tested | not tested | not tested | not tested |
| not tested | 100 | Rainbow Trout (Mortality at full strenght) | not tested | not tested | 100 | 100 | | |
| n/a | >100 | Inland Silversides IC25 % v/v | <6 25 | <6 25 | *7 8* | 7 5 | <6 25 | *7 3* |
| n/a | >100 | Inland Silversides LC50 % v/v | <6 25 | <6 25 | <6 25 | <6 25 | <6 25 | 13 2 |

# APPENDIX C
# HISTORICAL PHYSICAL AND CHEMICAL EFFLUENT CHARACTERISTICS CONCENTRATIONS

Background Data

| Type of processing | BOD | COD | TSS | FOG | TS | TKN | NH3-N | SS | O&G | P total | pH | PO4 | SO4 | NO3 | NH4 | Ref |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Units | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | | mg/L | mg/L | | | |
| Blue crab | 506-14000 | 566-25000 | 23-1000 | 150-220 | 18000-25000 | 1200 | 3.5-250 | | | 8.2 | 7.5-8.1 | | | | | 1,13,27 |
| Crab | 181-4100 | 320-29000 | 80-815 | | 1040-1814 | 23-166 | 6-13.6 | | | | | | | | | 24,25 |
| Shrimp | 112-2000 | 131-6500 | 22-2900 | 250-700 | 50-2000 | 22.4-196 | 1.8-13.8 | | | | | | | | | 1,3,23,24,25,26 |
| Clams | 500-2500 | 100-4000 | 200-6000 | 16-50 | | | | | | | | | | | | 1 |
| Oysters | 164-800 | 164-2000 | 50-2280 | 10 -- 30 | 240-400 | 22.4-91 | 2--10 | | | | | | | | | 1,22,23,25 |
| Scallops | 200-10000 | 300-11000 | 27-4000 | 15-25 | 9867 | 4200 | 15.5-37.5 | | | | | | | | | 1,23,28,29 |
| Mussel | | 18500 | 1070 | | 1400 | | | | | | 6 | 60 | 2040 | | | 7, 14 |
| Octopus | | 22000 | 1510 | | | | | | | | 6.3 | 210 | 2510 | | | 7 |
| Smoked squid | 960-10200 | 250-6100 | | | | | | 45-1200 | | | 6.3-7.5 | | | | | 12 |
| Shellfish | 280-4640 | 485-13440 | 125-825 | | 776-22300 | 36-45 | 6--15 | 180-5260 | | | | | | | | 17,22 |
| Lobster | 1500 | | | | | | | 980 | | | | | | | | 20 |
| Fish and shellfish | 310-3355.2 | 46-1284 | | | | 18-42 | | 79-1667.6 | | | 6.2-8.3 | 6.4-18.3 | | | 9.3-36 | 10,20,21,38 |
| Tuna | 500-895 | 1300-3250 | 500-1801 | 250-287 | 17900 | | | 1091 | | | | | | | | 1, 2, 17 |
| Salmon | 1.54-3970 | 300-9900 | 40-2735 | 20-550 | 68-3422 | 272-641.1 | | 0.26-22.6 | 239-1653 | | | | | | | 1,17,18,33,34 |
| Bottom and finfish (all) | 200-1000 | 400-2000 | 100-800 | 40-300 | | | | | | | | | | | | 1,15 |
| Herring | 360-17920 | 9600-64000 | 600-5000 | 600-800 | 264-2300 | | | 200-5833 | | | | | | | | 1,17,20 |
| Groundfish | 40-4000 | 213-9450 | 300-750 | | 1488-40000 | | | 14.4-1550 | 12.8-90 | | 7.1-9 | 0.005-3.95 | | 0.082-0.145 | | 2,17,18,37 |
| Canned finfish | 680-42000 | 2900-34500 | | | 700-19000 | 290-4000 | | 120-36000 | 120-2600 | 63-93 | 6.3-7.8 | | | | | 5,12,14,16 |
| Catfish | 340 | 700 | 400 | 200 | | | | | | | | | | | | 1 |
| Type of processing | BOD | COD | TSS | FOG | TS | TKN | NH3-N | SS | O&G | P total | pH | PO4 | SO4 | NO3 | NH4 | Ref |

| Units | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | | mg/L | mg/L | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | |
| Fish filleting | 327-1063 | | | | 1290-4300 | 34.4-149.2 | | | 47.6 | 4.78-20.78 | 7-8.3 | | | 0.72-26.13 | 0.021-2.56 | 8,11 |
| Canning, smoking and fish meal | 851-1167 | 1222-1431 | 3715-5071 | | | | 29-35 | | 215-400 | | | 13-17 | 0.2-0.55 | 4.7-6.2 | | 6 |
| Fish paste (surimi) | 510-8204 | 1210-18000 | | | 5120-7790 | 305-1100 | 15 | 390-2500 | | | 7.1-7.6 | | | | | 4,12,35 |
| Various fish (canned, marinated, salted, smoked) | 1402-4037 | 500-6634 | 200-6000 | | 422-5855 | 77-2452 | | | 150-1200 | | | | | | | 16,23,30, 31,32 |
| | | | | | | | | | | | | | | | | |
| Fish meal | 30-277000 | 150-190958 | 70-20000 | 20-5000 | 18530-107464 | 6414 | 86 | 131-23910 | 61.9-736 | | 6.35-8.1 | 1.12-220 | 540 | 0.106-0.151 | | 1,4,7,16, 17,36,37 |
| Stickwater | 38000-277000 | 48100-285000 | | | 45304-136824 | | | 2700-125000 | | | 6.3-7.36 | | | | | 17,18,19, 36 |
| Fish bloodwater | 19500-206000 | 39900-342200 | | | 53816-208940 | | | 1432-61550 | | | 5.45-7.09 | | | | | 9,17,18,3 6 |
| | | | | | | | | | | | | | | | | |
| Minimum | 1.54 | 46 | 22 | 10 | 50 | 18 | 1.8 | 0.26 | 12.8 | 4.78 | 5.45 | 0.005 | 0.55 | 0.082 | 0.021 | |
| Maximum | 277000 | 342200 | 20000 | 5000 | 208940 | 6414 | 250 | 125000 | 2600 | 93 | 8.1 | 220 | 2040 | 26.13 | 36 | |

## REFERENCES


1 – Carawan R.E., Chamber J.V., Zall R.R. and R. Wilkowske. 1979. Spinoff on seafood water and wastewater management. Extension Special Report No. AM-18F. north Carolina state University, Cornell University and Perdue University and Science and Education administration-Extension USDA Washington D.C.

2- Jones H.R. 1974. Pollution control in meat, poultry and seafood processing. Noyes Data corporation. Park Ridge, NJ.

3- Mauldin A.F. and A.J. Szabo. 1974. Shrimp canning waste treatment. Project S800904. Office of research and development. US EPA Washington DC.

4 - Carawan R.E. 1991. Processing Plant Waste Management guidelines. Seafood and the environment – 1991. Pollution Prevention Short Course. North Carolina state University.

5 – Anguiar A.L.C and G.L. Sant'Anna. 1988. Liquid effluent of the fish canning industries of Rio de Janeiro state – treatment alternatives. Env. Tech. Letters. Vol 9. 421-428.

6 – Fahim F.A., Fleita D.H., Ibrahim A.M. and F.M.S. El-Dars. 2001. Evaluation of some methods for fish canning wastewater treatment. Water, air and soil Pollution. 127: 205-226.

7 – Soto M., Mendez R. and J.M. Lema. 1991. Biodegradability and toxicity in the anaerobic treatment of fish canning wastewaters. Environmental Technology. 12(8): 669-677.

8- Gonzalez J.F., Civit E.M and H.M. Lupin. 1983 Lot more data Composition of fish filleting wastewater. Water South Africa; 9:49-56

9 – Civit E.M., Parin M.A. and H. M. Lupin. 1982. Recovery of protein and oil from fishery bloodwater waste. Water Res. 16: 809-814.

10 – Battistoni P. and G. Fava. 1994. Fish processing wastewater treatment requirements by line production change. Water Sci. Tech Vol. 29(9): 111-119.

11- Genovese C.V. and J.F. Gonzalez. 1998. Solids removal by coagulation form fisheries waste waters. Water South Africa. 24(4): 371-373

12 – Sano K. 1988. Treatment of waste water from marine products processing plants. Mar. Behav. Physiol. 14: 41-63.

13 – Geiger, E. L. Wheaton F.W., Brinsfield R.B. and J. E. Alleman. 1985. Biological treatment of crab processing plant wastewater. Journal WPCF. 57(12): 1128-1133.

14- Mendez R., F. Omil, Soto M. and J.M. Lema. 1992. Pilot plant studies on the anaerobic treatment of different wastewaters from a fish-canning factory. Water Sci. Tech. 25(1): 37-44.

15 – Ernst B., Hawkins V. and K.L. Tay. 1982. Investigation of the cause and extent of PCB contamination of Petit-de-Grat Harbour Nova Scotia. Environment Canada. EPS-5-AR-82-2

16 – Usydus Z. and P.J. Bykowski. 1998. Chemical characteristics of wastewater in the fish processing industry. Bull. Of the sea fisheries institute. 1(143): 63-73.

17 – Shafner. J. 1970. The various methods of reducing the waste material being discharged from the fish processing plants in Lameque, Shippagan and Caraquet, New Brunswick. A report to the New Brunswick Water authority.

18 – Riddle M.J. and K. Shikaze. 1973. Characterisation and treatment of fish processing plant effluents in Canada. Proc. : 4$^{th}$ Nat. Symp. On Food Processing Wastes, Washington DC.

19 McClare J. H. and Associates. 1987. development of UF/RO process for concentration of fishmeal plan stickwater. Report of a project carried out for Environment Canada.

20 – NBDELG 2003. from AMEC 2004

21 – NOAA. 1994. The national coastal pollution discharge inventory – gulf of Maine point source inventory: a summary by watershed for 1991. NOAA Strategic environmental assessment division.

22 – Hudson J.W. , Smith J.P. and F.G. Pohland. !976 Rotating biological contactor treatment of shellfish processing wastewaters. Proc. 31st Ind. Waste Conf. Perdue Univ.

23 – Delvane J.M. and J.M. Aguilera. 1990. Recovery of liquid by-products from fish meal factories: a review. Process Biochem. 25

24 – Tilsworth T. and W.D. Morgan. 1983. Alaska seafood processing industry. Proc. 38th Ind. Waste Conf, Perdue Univ.

25 – Horn C.R. and F.G. Pohland. 1973. Characterisation and treatability of selected shellfish processing wastes. Proc 28th Ind. Waste conf. Purdue Univ.

26 – NovaTec Consultants Inc. 1993. Wastewater handling in selected fish processing plants in Northern Europe – a report to the Fisheries Council of British Columbia.

27 Chao A.C., J.L. Machemehl and E. Galarranga. 1980. Proc 35th Ind. Waste conf., Perdue University.

28 – Krofta M., Wang L.K. and C.D. Pollman. 1988. Treatment of seafood processing wastewater by dissolved air flotation carbon adsorbtion and free chlorination. Proc. 43rd Ind. Waste conf. Purdue University.

29 Welsh F.W., Zall R.R. 1979. Fish scales: a coagulating aid for the recovery of food processing wastewater colloids. Process. Biochem. 16:4.

30 – Shifrin S.M., Pesenson I. B. and A.N. Zabbarov. 1972. Mechanical cleaning of wastewaters from fish canneries. Chem. Abs. 76.

31 – Pesenson I.B., Porkhal E.V., Baranova A.P. and A.N. Zabbarov. 1974. Composition of waste water from fish-processing plants. Chem. Abs. 81.

32- Ziminska H. 1985. Protein recovery from fish wastewaters. Agricultural waste utilization and management. Proc. 5th intern. Symp. On Agricultural waste.

33 – Clagget F.G. The use of chemical treatment and air flotation for the clarification of fish processing plant wastewater. Proc 3rd Nat. symp. On Food Processing Wastes.

34 – Stone F.E., Barnett H.J., Hunter P.J., Roberts J.C. and R. W. Nelson. 1981. Processing wastewater from two mechanised salmon canneries. Marine fisheries Review: 21-25.

35 – Green D., Tzou L., Chiao A.C. and T.C. Lanier. 1984. Strategies for handling soluble wastes generated during minced fish 9surimi) production. Proc. 39th ind. Waste conf. Purdue University.

36 Nutt S. 1974. Maritime Fish processing plant effluent study. Economic and Technical Review. EPS 3-WP-74-2

# APPENDIX D
# CALCULATIONS OF LOADINGS

Molluscs and crustaceans

Plant Id is a lobster processing plant which transforms up to 15 000lbs of lobster/shift (Table 4.3). This plant uses up to 527 US gallons/ minute on three different processing lines. In the following calculations, we assume that a third of this volume flows out of the lobster processing line over an 8 hour shift. Over a processing day, 319030 litres of water is expected to flow out as effluent form the lobster processing line.

Table 4.3. Calculation of Loading for plant Id

| Parameter | [ ] in effluent (mg/L) | Total output/ day (kg)[1] | Output/ tonne of product processed (kg/tonne)[2] | EPA effluent limitations guidelines for lobster |
|---|---|---|---|---|
| O&G | 14 | 4.4 | 0.64 | n/a |
| BOD | 204 | 65.08 | 9.5 | n/a |
| TSS | 79 | 25.31 | 3.71 | n/a |

[1]The total output in the table above is calculated by multiplying the number of litres of effluent by the concentration of the specific parameter in the composite sample collected by Environment Canada

[2]This value is calculated by using the amount of product processed per day as well as the total output/day calculated in the preceding column.

Plant Ia is a Jonah crab processing plant which transforms up to 20000lbs/day (9090.90kg) (Table 4.4). This plant uses up to 527 US gallons/ minute on three different processing lines. In the following calculations, we assume that a third of this volume flows out of the crab processing line over an 8 hour shift. Over a processing day, 319030 litres of water is expected to flow out as effluent form the crab processing line.

Table 4.4. Calculation of Loading for plant Ia

| Parameter | [ ] in effluent (mg/L) | Total output/ day (kg)[1] | Output/ tonne of product processed (kg/tonne)[2] | EPA effluent limitations guidelines for Dungeness and Tanner crab (kg/tonne)[3] |
|---|---|---|---|---|
| O&G | 1 | 0.32 | 0.35 | 0.1 (0.25) |
| BOD | 162 | 5.1 | 5.7 | 4.1 (10) |
| TSS | 179 | 5.7 | 6.3 | 0.69 (1.70) |

[1]The total output in the table above is calculated by multiplying the number of litres of effluent by the concentration of the specific parameter in the composite sample collected by Environment Canada

[2]This value is calculated by using the amount of product processed per day as well as the total output/day calculated in the preceding column.

[3] The values are average of daily values for 30 consecutive days and daily maximum (in parenthesis)

Plant Ib is a scallop processing plant which transforms up to 225 tonnes/day (80% of scallop landings in NS) (Table 4.5). This plant uses up to 527 US gallons/ minute on three different processing lines. In the following calculations, we assume that a third of this volume flows out of the scallop processing line over an 8 hour shift. Over a processing day, 319030 litres of water is expected to flow out as effluent form the scallop processing line.

| Table 4.5 Calculation of Loading for Plant Ib | | | | |
|---|---|---|---|---|
| Parameter | [ ] in effluent (mg/L) | Total output/ day (kg)[1] | Output/ tonne of product processed (kg/tonne)[2] | EPA effluent limitations guidelines for non-Alaskan scallop (kg/tonne) [3] |
| O&G | 0.5[4] | 0.16 | 0.00071 | 0.23 (7.3) |
| BOD | 82 | 26.16 | 0.11 | n/a |
| TSS | 56 | 17.87 | 0.079 | 1.4 (5.7) |

[1]The total output in the table below is calculated by multiplying the number of litres of effluent by the concentration of the specific parameter in the composite sample collected by Environment Canada

[2]This value is calculated by using the amount of product processed per day as well as the total output/day calculated in the preceding column.

[3] The values are average of daily values for 30 consecutive days and daily maximum (in parenthesis)

[4] This value is half the detection limit of the laboratory

Plant R

Plant R is a shrimp processing plant which transforms up to 75000 lbs/day (Table 4.6). This plant uses up to 450 US gallons/ minute over a 9 hour work day (on the day Environment Canada sampled). Over a processing day, 919755 litres of water is expected to flow out as effluent

| Table 4.6 Calculation of Loading for Plant R | | | | |
|---|---|---|---|---|
| Parameter | [ ] in effluent (mg/L) | Total output/ day (kg)[1] | Output/ tonne of product processed (kg/tonne)[2] | EPA effluent limitations guidelines for northern shrimp processing in the Contiguous States (kg/tonne) [3] |
| O&G | 93 | 85.54 | 2.51 | 5.7 (14) |
| BOD | 2062 | 1896.53 | 55.75 | 62 (155) |
| TSS | 479.4 | 440.93 | 12.96 | 15 (38) |

[1]The total output in the table below is calculated by multiplying the number of litres of effluent by the concentration of the specific parameter in the composite sample collected by Environment Canada

[2]This value is calculated by using the amount of product processed per day as well as the total output/day calculated in the preceding column.

[3] The values are average of daily values for 30 consecutive days and daily maximum (in parenthesis)

Groundfish

Plant M

Plant M is a cod processing plant which transforms up to 15000 lbs/day (Table 4.7). This plant uses up to 250 US gallons/ minute over a 4 hour shift (on the day Environment Canada sampled). Over a processing day, 227 100 litres of water is expected to flow out as effluent

| Table 4.7 Calculation of Loading for Plant M | | | | |
|---|---|---|---|---|
| Parameter | [ ] in effluent (mg/L) | Total output/ day (kg)[1] | Output/ tonne of product processed (kg/tonne)[2] | EPA effluent limitations guidelines for non-Alaskan mechanized bottom fish (kg/tonne)[3] |
| O&G | 6 | 1.36 | 0.20 | 0.47 (1.2) |
| BOD | n/a | | | |
| TSS | 77 | 17.48 | 2.56 | 7.5 (13) |

[1]The total output in the table below is calculated by multiplying the number of litres of effluent by the concentration of the specific parameter in the composite sample collected by Environment Canada

[2]This value is calculated by using the amount of product processed per day as well as the total output/day calculated in the preceding column.

[3] The values are average of daily values for 30 consecutive days and daily maximum (in parenthesis)

Plant L

Plant L is a redfish processing plant which transforms up to 20000 lbs/day (Table 4.8). This plant uses up to 300 US gallons/ minute over an 8 hour work day (on the day Environment Canada sampled). Over a processing day, 545040litres of water is expected to flow out as effluent

| Table 4.8. Calculation of Loading for Plant L | | | | |
|---|---|---|---|---|
| Parameter | [ ] in effluent (mg/L) | Total output/ day (kg)[1] | Output/ tonne of product processed (kg/tonne)[2] | EPA effluent limitations guidelines for non-Alaskan mechanized bottom fish (kg/tonne)[3] |
| O&G | 97 | 52.87 | 5.82 | 0.47 (1.2) |
| BOD | 118.6 | 64.64 | 7.11 | 7.5 (13) |
| TSS | 28 | 15.26 | 1.67 | 2.9 (5.3) |

[1]The total output in the table below is calculated by multiplying the number of litres of effluent by the concentration of the specific parameter in the composite sample collected by Environment Canada

[2]This value is calculated by using the amount of product processed per day as well as the total output/day calculated in the preceding column.

[3] The values are average of daily values for 30 consecutive days and daily maximum (in parenthesis)

Plant O

Plant O is a yellowtail flounder processing plant which transforms up to 50 tonnes/day (Table 4.9). This plant uses up to 2100 US gallons/ minute over an 8 hour work day (on the day Environment Canada sampled). Over a processing day, 3815280 litres of water is expected to flow out as effluent

| Table 4.9. Calculation of Loading for Plant O | | | | |
|---|---|---|---|---|
| Parameter | [ ] in effluent (mg/L) | Total output/ day (kg)[1] | Output/ tonne of product processed (kg/tonne)[2] | EPA effluent limitations guidelines for non-Alaskan mechanized bottom fish (kg/tonne) [3] |
| O&G | 42 | 160 | 0.32 | 0.47 (1.2) |
| BOD | 2415 | 9213.9 | 18.42 | 7.5 (13) |
| TSS | 549 | 2094.6 | 4.188 | 2.9 (5.3) |

[1]The total output in the table below is calculated by multiplying the number of litres of effluent by the concentration of the specific parameter in the composite sample collected by Environment Canada

[2]This value is calculated by using the amount of product processed per day as well as the total output/day calculated in the preceding column.

[3] The values are average of daily values for 30 consecutive days and daily maximum (in parenthesis)

Finfish

Plant H

Plant H is a salmon processing plant which transforms up to 4 000lbs of salmon/month (Table 4.10). The butchering project is not done on premises. Assuming 20 work days per month, we can calculate that the plant processes 2000lbs/day. This plant uses between 900 and 1600 $m^3$ of water per 3 month period. Over a 20 work day month, the average daily amount of water would be 15 000 litres/day (based on 900$m^3$).

| Table 4.10. Calculation of Loading for plant H | | | | |
|---|---|---|---|---|
| Parameter | [ ] in effluent (mg/L) | Total output/ day (kg)[1] | Output/ tonne of product processed (kg/tonne)[2] | EPA effluent limitations guidelines for West Coast mechanized salmon (kg/tonne) [3] |
| O&G | 81 | 1.21 | 1.33 | 1.5 (4.2) |
| BOD | 115 | 1.72 | 1.89 | 38 (62) |
| TSS | 85.5 | 1.28 | 1.41 | 7.6 (13) |

[1]The total output in the table below is calculated by multiplying the number of litres of effluent by the concentration of the specific parameter in the composite sample collected by Environment Canada

[2]This value is calculated by using the amount of product processed per day as well as the total output/day calculated in the preceding column.

[3] The values are average of daily values for 30 consecutive days and daily maximum (in parenthesis)

Plant S is a salmon processing plant which transforms up to 63 tonnes of salmon/day (Table 4.11). The butchering project is done on the premises. This plant uses up to 2900 gallons/hour. Over a 8 hour work day, the average daily amount of water would be 87 812 litres/day.

| Table 4.11. Calculation of Loading for plant S | | | | |
|---|---|---|---|---|
| Parameter | [ ] in effluent (mg/L) | Total output/ day (kg)[1] | Output/ tonne of product processed (kg/tonne)[2] | EPA effluent limitations guidelines for West Coast mechanized salmon (kg/tonne)[3] |
| O&G | n/a | n/a | n/a | 1.5 (4.2) |
| BOD | 101 | 8.86 | 0.14 | 38 (62) |
| TSS | 1280 | 112.4 | 1.78 | 7.6 (13) |

[1]The total output in the table below is calculated by multiplying the number of litres of effluent by the concentration of the specific parameter in the composite sample collected by Environment Canada

[2]This value is calculated by using the amount of product processed per day as well as the total output/day calculated in the preceding column.

[3] The values are average of daily values for 30 consecutive days and daily maximum (in parenthesis)

Plant U is a salmon processing plant which transforms up to 90 tonnes of salmon/day (Table 4.12). The butchering project is done on the premises. This plant uses up to 91 941 gallons/day. Over a 8 hour work day, the average daily amount of water would be 347996 litres/day.

| Table 4.12. Calculation of Loading for plant U | | | | |
|---|---|---|---|---|
| Parameter | [ ] in effluent (mg/L) | Total output/ day (kg)[1] | Output/ tonne of product processed (kg/tonne)[2] | EPA effluent limitations guidelines for West Coast mechanized salmon (kg/tonne)[3] |
| O&G | 16.6 | 5.77 | 0.06 | 1.5 (4.2) |
| BOD | 670 | 233.16 | 2.59 | 38 (62) |
| TSS | 514 | 178.86 | 1.98 | 7.6 (13) |

[1]The total output in the table below is calculated by multiplying the number of litres of effluent by the concentration of the specific parameter in the composite sample collected by Environment Canada

[2]This value is calculated by using the amount of product processed per day as well as the total output/day calculated in the preceding column.

[3] The values are average of daily values for 30 consecutive days and daily maximum (in parenthesis)

Plant G

Plant G is a herring processing plant which transforms up to 500 tonnes/day (Table 4.13). This plant uses up to 600 US gallons/ minute over a 16 hour work day (on the day Environment Canada sampled). Over a processing day, 2 180 160 litres of water is expected to flow out as effluent

| Table 4.13. Calculation of Loading for Plant G | | | | |
|---|---|---|---|---|
| Parameter | [ ] in effluent (mg/L) | Total output/ day (kg)[1] | Output/ tonne of product processed (kg/tonne)[2] | EPA effluent limitations guidelines for non-Alsakan herring fillet (kg/tonne) [3] |
| O&G | 296 | 645.32 | 1.29 | 1.1 (2.9) |
| BOD | 342 | 745.61 | 1.49 | 15(16) |
| TSS | 347 | 756.52 | 1.51 | 5.2 (7) |

[1]The total output in the table below is calculated by multiplying the number of litres of effluent by the concentration of the specific parameter in the composite sample collected by Environment Canada
[2]This value is calculated by using the amount of product processed per day as well as the total output/day calculated in the preceding column.
[3] The values are average of daily values for 30 consecutive days and daily maximum (in parenthesis)

Plant K

Plant K is a herring processing plant which transforms up to 24000lbs/day (Table 4.14). This plant uses up 1 000 000 US gallons over a 3 month period. Assuming 20 work days every month, 63 333 litres of water is expected to flow out as effluent on any given processing day.

| Table 4.14. Calculation of Loading for Plant K | | | | |
|---|---|---|---|---|
| Parameter | [ ] in effluent (mg/L) | Total output/ day (kg)[1] | Output/ tonne of product processed (kg/tonne)[2] | EPA effluent limitations guidelines for non-Alaskan herring fillet (kg/tonne) [3] |
| O&G | 33 | 2.09 | 1.91 | 1.1 (2.9) |
| BOD | 145 | 9.18 | 8.42 | 15(16) |
| TSS | 64 | 4.05 | 3.71 | 5.2 (7) |

[1]The total output in the table below is calculated by multiplying the number of litres of effluent by the concentration of the specific parameter in the composite sample collected by Environment Canada
[2]This value is calculated by using the amount of product processed per day as well as the total output/day calculated in the preceding column.
[3] The values are average of daily values for 30 consecutive days and daily maximum (in parenthesis)

Plant N

Plant N is a herring/ fish meal processing plant which transforms up to 100 tonnes/day (Table 4.15). Effluent output is not know at this plant but has been calculated as a ratio of products processed in comparison to a large herring plant. This plant processes only one fifth of the total herring processed by the other plant on an eight hour workday (instead of 16) and therefore, effluent is calculated a one fifth of the output from Plant G. Therefore, 218 016 litres of water is expected to flow out as effluent on any given processing day.

| Table 4.15. Calculation of Loading for plant N | | | | |
|---|---|---|---|---|
| Parameter | [ ] in effluent (mg/L) | Total output/ day (kg)[1] | Output/ tonne of product processed (kg/tonne)[2] | EPA effluent limitations guidelines for non-Alaskan herring fillet (kg/tonne) [3] |
| O&G | 97 | 21.2 | 0.212 | 1.1 (2.9) |
| BOD | 654 | 143.15 | 1.43 | 15(16) |
| TSS | 697 | 152 | 1.52 | 5.2 (7) |

[1]The total output in the table below is calculated by multiplying the number of litres of effluent by the concentration of the specific parameter in the composite sample collected by Environment Canada

[2]This value is calculated by using the amount of product processed per day as well as the total output/day calculated in the preceding column.

[3] The values are average of daily values for 30 consecutive days and daily maximum (in parenthesis)